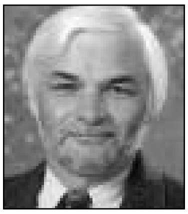
# Virtual reality

DAVID ROSE *and* NIGEL FOREMAN *describe the application to psychology of a fast-developing new technology.*

WHAT we now know as virtual reality (VR) had its origins in the development of 'visually coupled' systems (Kalawsky, 1993), which formed the basis of the first flight simulators. This is a computer technology that allows us to present people with a computer-generated environment within which they can move around and with which they can interact.

The nature of the virtual environment (VE) is determined by the programmer: it could be the cockpit of an aircraft, a building, a ski slope or a games environment.

In the conventional and well-known form of VR, the visual and auditory aspects of the VE are conveyed to the participant through visual display units and speakers in the head-mounted display (HMD). Tactile sensation is transmitted through heat and pressure pads mounted in data gloves or a body suit.

Movements within the environment, detected by sensors in the HMD, data gloves and body suit and by a hand-held 3-D mouse, cause the computer to alter the sensory stimulation accordingly.

VR in this comprehensive and multisensory sense can be extremely expensive, and aspects of it require considerable further development. However,VR also comes in a cheaper form. Here the visual aspects of the VE are delivered via a PC monitor, and the participant moves around the environment by using a joystick or similar device.

Participants typically experience less of a sense of being 'immersed' in the VE, since they continue to receive significant amounts of sensory information from the real environment. Often, this PC screen-based VR is referred to as 'non-immersive' VR. However, the sense of immersion can be increased both by viewing the screen through stereoscopic glasses and by increasing the size of the screen and reducing the background lighting.

Recent years have seen a dramatic growth in the development of VR applications — for example, in engineering, architecture, design, education and training and in a variety of military contexts. Psychologists, in our opinion, have been relatively slow to appreciate its great potential.

The ability to isolate people from their normal sensory environments, and to substitute computer-generated environments which are infinitely flexible, entirely controllable and within which behaviour can be monitored in great detail, must be of interest to psychologists. In this article, we shall both look at some of the ways psychologists are currently using VR and highlight the drawbacks and unknowns of this technology.

## VR as a research tool

At its simplest,VR can be seen as a technology offering a novel method of presenting stimuli to participants in psychological research.

Over the years, experimental psychologists have used a variety of stimulus displays in their work (word and number lists, text, diagrams, drawings, photographs and video). Computerisation has allowed for more flexible and interactive displays; VEs may be seen as the next step in this line of development. As we have noted, a VE is interactive, and it can be multisensory. It can be a complex, large-scale environment, yet, crucially, the experimenter retains complete control over the sensory array that the participant experiences.

Perhaps the most obvious contribution VR can make to research is in elucidating the importance, in terms of cognitive processing, of active interaction with an environment rather than passive observation of it. A number of studies have sought to exploit VR's potential in this regard, although so far with mixed findings.

In terms of spatial learning, the conventional superiority of active over passive interaction with a real-world situation has not always been found in VEs (Wilson, 1997). However, some differences between active and passive involvement in a virtual world have been reported. For example, Brooks *et al.* (1999) found that object and spatial memory are differentially affected by active versus passive VR experience.

Spatial research, which has traditionally used static test environments, has much to gain from the use of VR (Wilson, 1997). Indeed, the software used to create VEs has sometimes been referred to as 'soft-where', given its essentially spatial nature.

Ruddle *et al.* (1997) have examined exploration of 3-D buildings, using a virtual reconstruction of an environment previously used in a study of spatial cognition (Thorndyke & Hayes-Roth, 1982), with comparable results. The use of landmarks in virtual route learning has been addressed via cue manipulations that are difficult or impracticable in real environments (Tlauka & Wilson, 1994). Tasks used in assessment can benefit from the unique features of VR, such as instantaneous viewpoint shifts.

VR allows various forms of augmentation to be used to enhance attention and learning. For example, elements within complex VEs can be artificially highlighted, magnified, coloured, labelled or otherwise accentuated. Access can be improved by stripping away irrelevant information, and scale can be manipulated for instructional purposes. Where 3-D stimuli are required, but where context is irrelevant, as in studies of mental rotation, VR may be especially useful (Rizzo & Buckwalter, 1997).

VR environments can be combined with other technologies. Decety *et al.* (1994) have studied motor representation within the brain by examining the PET (positron emission tomography) scans of participants in a virtual motor task. Maguire *et al.* (1998) have shown that there is selective activation of the right parahippocampal gyrus when individuals learn about salient landmarks during navigation in a large-scale virtual space. Electrophysiological correlates of activity within a VE have also been recorded (Pugnetti *et al.,* 1994).

VR, then, allows direct measures of nervous system activity to be made during ongoing environmental interaction. This holds considerable promise for neuroscience research.

## Virtual environments as a training medium

After interactive computer games, training has probably been the fastest growing area of application of VR (Durlach & Mavor, 1995; Psotka, 1995). VEs have already been developed for the training of pilots, drivers, divers, parachutists, firefighters, console operators, and surgeons and other medical staff .

VEs have also been used to train naval officers in ship manoeuvres (Magee, 1997), soldiers in battlefield simulations (Goldberg & Knerr, 1997), and the Hubble space telescope ground control team to familiarise themselves with the operability of the telescope's component parts (Loftin *et al.*, 1997).

With the aid of VEs, dangerous operations can be trained in complete safety, and difficult tasks repeatedly rehearsed. Improvement in performance can be monitored very precisely and task difficulty can be accurately and finely adjusted. Moreover, environmental simulations are transportable on diskette, obviating the need for moving bulky equipment.

Compared with diagrams and manuals, VR is realistic (pilots are reported to emerge from virtual near-accidents in an emotional state). Compared with videos and CD-ROMs, it is more interactive; and, compared with trainers and supervisors, it is cheap.

An exciting area of development in recent years, and one in which psychologists have been instrumental, is the use of VEs for training within therapy and rehabilitation. There is, for instance, a growing literature on the use of VEs in desensitisation training for people with phobias (e.g. North *et al.*, 1997).

Some success has also been reported in using VEs for training people with learning difficulties. For example, Cromby *et al.* (1996) have given teenagers with learning disabilities experience of virtual supermarket shopping.

The teenagers were required to move to appropriate locations in the shop and mouse-click on items on the shelves; these were later available at the checkout for virtual purchase. They were better able to find the locations of particular items, and were more economic in their movements in the shop, following VR experience than non-specific experience.

Equally successful was the intervention reported by Mowafy and Pollack (1995), who devised a virtual bus route to train people with cognitive impairments to use the real bus. A measure of their success was a saving of 15 hours of the tutor's time in getting students to a predefined level of performance on the real-world task.

Other examples of VR-based training within therapy and rehabilitation include: using VEs to train recognition and tracking skills in children with autism (Strickland, 1997); spatial skills in children with motor disorders (Stanton *et al.*, 1998); and for rehabilitation of people with various types of brain damage (e.g. Rizzo & Buckwalter, 1997).

In these instances, an important advantage of VEs is that interactions with the environment can be made contingent on the response repertoire of the individual. Consequently, people whose motor disabilities restrict their activities in real-world environments can still interact with virtual training environments. Similarly, a virtual environment can be structured to offset partial sensory loss in the user.

Quite apart from any training effect, the interaction with an environment that VR affords may have beneficial effects on the damaged nervous system (Rose *et al.*,

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James Woods in David Cronenberg's **Videodrome**

1998), in the way that environmental enrichment is assumed to do in brain-lesioned animals (Will & Kelche, 1992).

### VR in assessment

Precisely those characteristics of VEs that lend themselves to training applications also suggest VR should have great potential in assessment (Andrews *et al*., 1995). For example, within clinical neuropsychology there has been a long-running debate about the ecological validity of conventional tests (Neisser, 1978).

Traditionally, the choice has been between rigorously controlled but artificial test situations and real-life test situations. The latter have the merit of greater ecological validity, but are usually seen as lacking scientific rigour.

This debate has resulted in a number of 'everyday' tests of cognitive function (for example, Wilson *et al*., 1985), a development to which VR has the potential to make a considerable contribution. In a VE, it is possible to combine both realism and rigorous scientific control.

As noted above, an additional advantage of using VEs as test situations is that responses within such environments can be made conditional on a variety of motor responses. So it is possible to measure cognitive processes in people whose motor impairments might otherwise present a considerable barrier to accurate assessment. Similarly, aspects of the environmental display can be accentuated to offset partial sensory loss in the person being tested.

### Evaluation: The limitations of VR technology

VR has always suffered from media hype. The point was succinctly made in a major report that noted that for VR 'the excitement to accomplishment ratio' remains high (Durlach & Mavor, 1995). We would not wish to make matters worse here. VR is no panacea: it has its limitations.

At the practical level, we have already hinted at some of the difficulties. The body suits and data gloves, so essential to fully immersive multisensory VR, are still in need of further development. Even the best developed part of the stimulus delivery system, the HMD, has limitations in image quality and field of view.

Screen-based VR gives a higher-resolution visual image, but is even more limited in terms of visual field width. It also creates less feeling of immersive presence because of the absence of proprioceptive feedback.

Given their respective limitations, whether to use HMD-based or screen-based VR must depend on the purpose in mind. Ruddle *et al.* (1997) reported that exploration is more efficient and straight-ahead distance judgements more accurate with HMDs than screen-based systems, though directional estimates were no better. As yet, however, there have been relatively few systematic comparisons of HMD and screen-based VR systems in terms of the ways in which participants respond to them.

Cost may also be a limiting factor. In fact, whilst embarking on VR research can be very expensive, the equipment for creating and using quite complex VEs need not be. The cost is largely in providing backup technical support and experienced programmer time. So, many departments, schools and hospitals would be hard pressed to afford VR without generous grant support. Given the costs involved, it is important, when considering the use of VR, to be sure that cheaper methods (video, for example) could not be used for the intended purpose.

Exposure to immersive VR can cause nausea, dizziness and visual disturbances (see e.g. Rizzo, *et al*. 1998). This may result from the inevitable delay that occurs between participant-initiated movement and the consequent updating of the screen display, creating visual-vestibular asynchrony. The delay (in which time the screen display is redrawn and rerendered) is usually small, and varies with the complexity of the current scene.

Participants do not always report these effects, and those who do suffer nausea on first exposure to immersive VR appear to adapt on subsequent exposures. Even so, these unwanted side-effects of VR do raise some ethical concerns.

It is likely that VR will not prove to be an appropriate medium for everyone. Clearly, care must be taken with participants who report side-effects. Others, for a variety of reasons, may choose not to be exposed to VEs, especially immersive

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ones, and there may be some psychiatric service users for whom this sort of experience is not judged to be a good idea.

Finally, there have been suggestions, as with interactive computer games, that virtual experiences may prove to be addictive. Whilst there is no evidence of this being the case at present, it is a possibility which must be borne in mind. Other ethical issues may well emerge as we learn more about the nature of cognitive processing within a VE.

For example, a particular learning experience in a VE might appear to be entirely positive. But we need to be aware that some learning might be occurring that could prove dangerous if transferred to the real world. Individuals who are taught road-crossing skills in VEs might transfer those experiences to real environments and treat road crossing casually, having experienced non-injurious virtual collisions.

At a more theoretical level, the application of VR to the sorts of

## FURTHER INFORMATION

There is now an extensive literature on VR and its applications that space does not permit us to describe here. However, for those interested in investigating VR further, we have set up a web page, accessible on www.uel.ac.uk/psychology/verat.

psychological contexts we have described may seem paradoxical. It is claimed that VR is of value because it can be used for assessment and training that could not be carried out in the real world (or only with great difficulty or at some risk or both). However, without the ability to check outcomes against those from the equivalent real-world environment, how can we be sure participants are responding in a similar manner in the two situations?

We must be aware that perceptual and sensorimotor behaviour in the virtual and real worlds may be significantly different. Similarly, cognitive loads associated with processing information in real and virtual environments might not be the same.

The issue is primarily one of the ecological validity of VEs. Virtual and real worlds are clearly different. So, what are the elements of VEs that mimic reality sufficiently to elicit cognitive processing comparable to that which takes place in the real world? Many have argued that the important characteristic is ‘presence’— the sense of being in the environment (Steuer, 1992). However, the question is one that is, as yet, poorly understood.

A related issue is that of transfer of training. If VR is to be used as a training medium, it is important to understand the process of transfer between virtual and real environments.

In the training of spatial skills, positive transfer from virtual to real environments has generally been reported (e.g. Arthur *et al.*, 1997). In the case of procedural learning, early studies cast doubt on whether transfer from virtual to real environments would occur (Kozak *et al.*, 1993). However, this finding has been questioned on methodological grounds (Durlach & Mavor, 1995) and disputed by later investigations (Kenyon & Afenya, 1995). Recent studies (see e.g. Regian, 1997) have found clear evidence of positive transfer of procedural learning from virtual to real environments.

However, there is a need for further systematic investigation of the types of learning which transfer, the extent to which they transfer and the factors influencing the extent of that transfer. The answers for HMD-based and screen-based VR may not be the same, of course.

Although VR is a product of computer technology, its use raises essentially psychological issues: how people behave, feel and acquire information in illusory virtual worlds. Clearly, there is no purpose in employing VR unless the behavioural side has been validated.

VR has been described as ‘a solution looking for a problem’(Riva, 1997); in recent years, the problems have come forward and there is no shortage of agencies offering VR as solutions. However, it is possible that some of the ‘behavioural’areas in which VR is claimed to have potential are technology-driven rather than psychology-led.

Despite the current limitations and the issues surrounding its use discussed above, it would seem that VR is poised to answer a number of important research questions in psychology.

Equally, developing its application to the fields of assessment, training, rehabilitation and therapy promises significant advances in these fields. Recently, for example, VR applications to the assessment and treatment of eating disorders (Riva *et al.*, 1998), treatment of sexual dysfunction (Optale *et al.*, 1998) and palliative medicine (Oyama, 1998) have been suggested.

Looking further ahead still, VR holds the promise of many more contributions to psychological research and applications, for example, through the development of networked virtual environments.

The ‘accomplishment to excitement ratio’ for VR is on the up and will rise ever more steeply in the next five years.

## References


Andrews, T.K., Rose, F.D., Leadbetter, A.G., Attree, E.A. & Painter, J. (1995). The use of virtual reality in the assessment of cognitive ability. In I. Placencia Porrero & R. Puig de la Bellacasa (Eds), *The European Context for Assistive Technology*. Amsterdam: IOS Press.

Arthur, E.J., Hancock, P.A. & Chrysler, S.T. (1997). The perception of spatial layouts in real and virtual worlds. *Ergonomics*, 40, 69–77.

Brooks, B.M., Attree, E.A., Rose, F.D., Clifford, B.R. & Leadbetter, A.G. (1999). The specificity of memory enhancement during interaction with a virtual environment. *Memory*, 7, 65–78.

Cromby, J.J., Standen, P.J., Newman, J. & Tasker, H. (1996). Successful transfer to the real world of skills practised in a virtual environment by students with severe learning disabilities. In P.M. Sharkey (Ed.), *Proceedings of the First European Conference on Disability, Virtual Reality and Associated Technologies*. Reading: ECDVRAT and the University of Reading.

Decety, J., Perani, D., Jeannerod, M., Bettinardi, V., Tadary, B., Woods, R., Mazziotta, J.C. & Fazio, F. (1994). Mapping motor representations with positron emission tomography. *Nature*, 371, 600–602.
Durlach, N.I. & Mavor, A.S. (Eds) (1995). *Virtual Reality: Scientific and Technical Challenges.* Washington: National Academy Press.
Goldberg, S. & Knerr, B.W. (1997). Collective training in virtual environments: Exploring performance requirements for dismounted soldier simulation. In R.J. Seidel & P.R. Chantelier (Eds), *Virtual Reality: Training's Future.* New York: Plenum.
Kalawsky, R.S. (1993). *The Science of Virtual Reality and Virtual Environments.* Wokingham: Addison-Wesley.
Kenyon, R.V. & Afenya, M.B. (1995). Training in virtual and real environments. *Annals of Biomedical Engineering*, 23, 445–455.
Kozak, J.J., Hancock, P.A., Arthur, E.J. & Chrysler, S.T. (1993). Transfer of training from virtual environments. *Ergonomics*, 36, 777–784.
Loftin, R.B., Savely, R.T., Benedetti, R., Culbert, C., Pusch, L., Jones, R., Lucas, R., Muratore, J., Menninger, M., Engelbert, M., Kenney, P., Nguyen, L., Saito, T. & Voss, M. (1997). Virtual environment technology in training: Results from the Hubble space telescope mission in 1993. In R.J. Seidel & P.R. Chantelier (Eds), *Virtual Reality: Training's Future.* New York: Plenum.
Magee, L.E. (1997). Virtual reality simulator (VRS) for training ship handling skills. In R.J. Seidel & P.R. Chantelier (Eds), *Virtual Reality: Training's Future.* New York: Plenum.
Maguire, E.A., Frith, C.D., Burgess, N., Donnett, J.G., O'Keefe, J. & Frith, C.D. (1998). Knowing where things are: Parahippocampal involvement in encoding object locations in virtual large-scale space. *Journal of Cognitive Neuroscience*, 10, 61–76.
Mowafy, L. & Pollack, J. (1995). Train to travel. *Ability*, 15, 18–20.
Neisser, U. (1978). Memory: What are the important questions? In M.M. Gruneberg, P.E. Morris & R.N. Sykes (Eds), *Practical Aspects of Memory*. London: Academic Press.
North, M.M., North, S.M. & Coble, J.R. (1997). Virtual reality therapy: An effective treatment for psychological disorders. In G. Riva (Ed.), *Virtual Reality in Neuro-Psycho-Physiology*. Oxford: Oxford University Press.
Optale, G., Munari, A., Nasta, A., Pianon, C., Baldaro Verdi, J. & Viggiano, G. (1998). A VR based therapy for the treatment of impotence and premature ejaculation. In G. Riva, B.K. Wiederhold & E. Molinari (Eds), *Virtual Environments in Clinical Psychology and Neuroscience.* Amsterdam: IOS Press.
Oyama, H. (1998). Virtual reality for palliative medicine. In G. Riva, B.K. Wiederhold & E. Molinari (Eds), *Virtual Environments in Clinical Psychology and Neuroscience.* Amsterdam: IOS Press.
Psotka, J. (1995). Immersive training systems: Virtual reality and education and training. *Instructional Science*, 23, 404–431.
Pugnetti, L., Mendozzi, L., Cattaneo, A., Guzetti, S., Mezetti, C., Coglati, C., Dell'Abate, E., Brancotti, A. & Venanzi, D. (1994). Psychophysiological activity during virtual reality testing. *Journal of Psychophysiology*, 8, 361–362.
Regian, J.W. (1997). Virtual reality for training: Evaluating transfer. In J. Kreutzer & P. Wehman (Eds), *Community Integration Following Traumatic Brain Injury: A Functional Approach.* Baltimore, MD: Paul H. Brookes.
Riva, G. (Ed.) (1997). *Virtual Reality in Neuro-Psycho-Physiology.* Amsterdam: IOS Press.
Riva, G., Bacchetta, M., Baruffi, M., Rinalsi, S. & Molinari, S. (1998). Experiential cognitive therapy: A VR based approach for the assessment and treatment of eating disorders. In G. Riva, B.K. Wiederhold & E. Molinari (Eds), *Virtual Environments in Clinical Psychology and Neuroscience.* Amsterdam: IOS Press.
Rizzo, A.A. & Buckwalter, J.G. (1997). Virtual reality in cognitive assessment and rehabilitation: The state of the art. In G. Riva (Ed.), *Virtual Reality in Neuro-Psycho-Physiology.* Amsterdam: IOS Press.
Rizzo, A.A., Wiederhold, M.D. & Buckwalter, J.G. (1998). Basic issues in the use of virtual environments for mental health applications. In G. Riva, B.K. Wiederhold & E. Molinari (Eds), *Virtual Environments in Clinical Psychology and Neuroscience.* Amsterdam: IOS Press.
Rose, F.D., Attree, E.A., Brooks, B.M. & Johnson, D.A. (1998). Virtual environments in brain damage rehabilitation: A rationale from basic neuroscience. In G. Riva, B.K. Wiederhold & E. Molinari (Eds), *Virtual Environments in Clinical Psychology and Neuroscience.* Amsterdam: IOS Press.
Ruddle, R.A., Payne, S.J. & Jones, D.M. (1997). Navigating buildings in 'desk-top' virtual environments: Experimental investigations using extended navigational experience. *Journal of Experimental Psychology: Applied*, 3, 143–159.
Stanton, D., Foreman, N. & Wilson, P.N. (1998). Uses of virtual reality in training: Developing the spatial skills of children with mobility impairments. In G. Riva, B.K. Wiederhold & E. Molinari (Eds), *Virtual Environments in Clinical Psychology: Scientific and Technical Challenges in Advanced Patient–Therapist Interaction.* Amsterdam: IOS Press.
Steuer, J. (1992). Defining virtual reality: Dimensions determining telepresence. *Journal of Communication*, 42, 73–93.
Strickland, D. (1997). Virtual reality for the treatment of autism. In G. Riva (Ed.), *Virtual Reality in Neuro-Psycho-Physiology.* Amsterdam: IOS Press.
Thorndyke, P.W. & Hayes-Roth, B. (1982). Differences in spatial knowledge acquired from maps and navigation. *Cognitive Psychology*, 14, 560–589.
Tlauka, M. & Wilson, P.N. (1994). The effect of landmarks on route learning in a computer-simulated environment. *Journal of Environmental Psychology*, 14, 305–315.
Will, B.E. & Kelche, C. (1992). Environmental approaches to recovery of function following brain damage: A review of animal studies (1981–1991). In F.D. Rose & D.A. Johnson (Eds), *Recovery from Brain Damage: Reflections and Directions.* New York: Plenum.
Wilson, B.A., Cockburn, J. & Baddeley, A.D. (1985). *The Rivermead Behavioural Memory Test.* Titchfield, Hants: Thames Valley Test Company.
Wilson, P. (1997). Virtual reality in spatial learning research. In N. Foreman & R. Gillett (Eds), *A Handbook of Spatial Research Paradigms and Methodologies*, vol.1. Hove: Psychology Press.

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