A decade of research and development in disability, virtual reality and associated technologies: promise or practice?

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ABSTRACT

The International Conference on Disability, Virtual Reality and Associated Technologies (ICDVRAT) this year holds its sixth biennial conference and celebrates ten years of research and development in this field. A total of 180 papers have been presented at the first five conferences, addressing potential, development, exploration and examination of how these technologies can be applied in disabilities research and practice. The research community is broad and multi-disciplined, comprising a variety of scientific and medical researchers, rehabilitation therapists, educators and practitioners. Likewise, technologies, their applications and target user populations are also broad, ranging from sensors positioned on real world objects to fully immersive interactive simulated environments. A common factor is the desire to identify what the technologies have to offer and how they can provide added value to existing methods of assessment, rehabilitation and support for individuals with disabilities. We review this first decade of research and development in the ICDVRAT community and ask how far we have progressed: are we still discussing potential and promise or has our technology found its way into practical implementation?

1. INTRODUCTION

The first European Conference on Disability, Virtual Reality and Associated Technologies (ECDVRAT) was held in the UK in 1996. 30 papers were presented. Keynote addresses described the increasing interest in virtual reality technology for disabilities (Murphy, 1996), potential application in neurological rehabilitation (Rose, 1996) and as a means of providing access to computer information for users with visual impairment (Zwern and Goodrich, 1996). The second ECDVRAT was held in Sweden in 1998, establishing the biennial timing of the conference, whilst the international attendance in ’96 and ’98 prompted a change in title from ‘European’ to ‘International’ for the 2000 conference, held in Alghero, Sardinia. A chance contribution of an essay on the coastal region of Alghero led to a now traditional essay on the host town for each conference since: Veszprém (Hungary, 2002), Oxford (UK, 2004) and Esbjerg (Denmark, 2006).

As an applied research area, the ICDVRAT community includes practitioners, educators, researchers, technologists and end users from schools, hospitals, disability service providers, rehabilitation institutes academic research, scientific institutes and technology development labs drawn from a variety of disciplines including; medicine, healthcare, education, computer science, psychology and engineering. Papers presented at ICDVRAT describe technology development, design, evaluation and impact of virtual reality and associated technologies via individual case studies, experimental studies and large scale multi-centre research projects.

This paper celebrates 10 years of ICDVRAT by presenting a representative review of papers presented over the past decade, organised around three central themes:

- Virtual Reality and Associated Technologies – what are they?
- Disability – for what user populations have these technologies been developed?
- Application usage – how has the technology been applied?

We conclude by examining the ICDVRAT literature to see what changes have occurred over the last decade and pose the question: is this a technology in practice or are we still just offering promise?

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For reasons of brevity, key aspects of technology development and application are described only. We apologise to authors whose papers are not represented in this review, it was not possible to include them all.

2. VIRTUAL REALITY AND ASSOCIATED TECHNOLOGIES

2.1 3D Virtual Environments

The predominant technology applied in ICDVRAT is Virtual Reality (VR) or Virtual Environments (VEs). These are computer-generated three-dimensional environments that can be explored and interacted with in real-time. The most commonly–used VE development platform is Superscape™ and this has mostly been used to construct representations of pseudo and actual real-world environments for training, education and performance assessment purposes. Other VE development platforms used are: dVISE, VRML, WorldUp, World Toolkit, HalfLife, Macromedia Director and Shockwave.

These VEs can be displayed via standard desktop PC delivery, Head-Mounted Displays (HMD), single screen projection, or CAVE™–type multiple screen projection systems, an example of which is the University of Reading's ReaCTor, as illustrated on the back cover of this Proceedings. The majority of virtual environments have been presented via desktop displays although some researchers have used the specific advantages of HMD and projected displays to provide an 'immersion' experience. More bespoke display systems have also been presented such the Immersadesk and the University of Southern California's panoramic display suite. While use of such systems is limited by budget a recent theme has developed in the use of simple technology and widely available toy/game interfaces such as the EyeToy for rehabilitation programmes.

2.2 Multimedia

Virtual environments do not need to be 3D and 2D projected environments can also provide a sense of 'immersion' or 'engagement'. For some applications, such as spatial navigation training of real places, video images of the real world are more appropriate and a lot easier to generate than computer simulation models. The level of video capture has ranged from full 360° panorama scenarios with virtual characters inserted into the scenes for anger management and treatment of social phobias (e.g. Rizzo et al., 2004), the VividGroup's Gesture Xtreme (GX) system, to the use of the EyeToy and simple video capture to develop very low cost systems for physiotherapy following stroke (e.g. Rand, Kizony and Weiss, 2004).

2.3 Multi-sensory and acoustic environments

Virtual environments do not need to be visual. Considerable research has been conducted to develop acoustic environments. First presented as a concept design in 1996, it was not clear whether it was possible to render 3D sound in real time (Lumbreras, Barcia and Sánchez, 1996). The existing acoustic technology formats were not appropriate for 3D surround sound to enable accurate perception of sound direction and Keating (1996) demonstrated use of the ambisonic-B format. In 1998, Lumbreras and Sánchez presented results showing that spatialised sound could be used to stimulate diminished cognitive skills in blind children and can be further used to assist in navigation.

Winberg and Hellström (2000) demonstrated the possibility of auditory direct manipulation with the sonified Towers of Hanoi task. This was promising evidence that acoustic environments could provide access to computers for blind users, although this had not been tested with blind users. The spatial audio system (Kurniawan et al., 2004) demonstrated that blind users could differentiate sounds representing sound effects created in a small, medium or large real or virtual room, indicating that the sound algorithms were appropriate.

Tony Brooks et al. (2002) showed that the term 'virtual environments' need not be restricted to a limited notion of an architecturally understandable space, but can be realised as a more visually and sonically abstract space that can enhance quality of life for severely disabled children.

2.4 Interaction methods

Different technologies have been used to provide interaction with virtual environments. These include standard PC interaction devices (keyboard, mouse and joystick), VR specific interaction devices for interaction and navigation with a 3D virtual environment (data gloves, HMD and tracker systems), and specialised technologies developed or adapted for ICDVRAT users. Examples include augmented reality systems to integrate technologies for home-based rehabilitation (Hammond, Sharkey and Foster, 1996), eye-tracking technology for gaze-control interaction (Istance et al., 1996; Bates and Istance, 2004), whole body movement, and tangible interfaces. Tangible interfaces have included navigation controlled via an exercise bike (Johnson, Rushton and Shaw, 1996), a wheelchair (Harrison et al., 2000), and tethered kitchen items (Hilton et al., 2002).

Gesture recognition technologies have been developed using cyberglove and position sensors for sign language input (Vamplew, 1996; Kuroda, Sato and Chihara, 1998; Sawada, Notsu and Hashimoto, 1998) and camera-vision systems for either modelling of hand-gesture for communication (García-Ugalde, Gatica-Pérez and García-Garduño, 1998) or for interaction with the real world (Foyle and McCrindle, 2004; Pridmore et al., 2004).

2.5 Haptic, force-feedback and tactile devices

Tactile feedback to users has been explored using tactile tablets (Eves and Novak, 1996; Sánchez and Flores, 2004), the Impulse Engine force-feedback device (Colwell et al., 1998), a vibrotactile actuator (Langdon et al., 2000), force-feedback mouse (Langdon et al., 2002; Caffrey and McCrindle, 2004) and force-feedback joysticks (Conner et al., 2002; Sánchez and Flores, 2004).

The most explored haptic device has been the PHANToM haptic stylus used for tactile exploration of 3D data (Jansson, 1998; Jansson 2000; Petrie et al., 2000, Wall and Brewster, 2004) and assessment and rehabilitation of fine manual dexterity (Broeren et al., 2002). The InMotion2 Robot with graphic display was also developed for motor control, providing tele-assessment and co-operative rehabilitation (in which the patient's robot mimics the clinician's robot) of hand/arm movement (Olsson, Carignan and Tang, 2004).

2.6 Wheelchair-mounted devices

A range of sensors have been mounted onto wheelchairs to provide navigation feedback and obstacle detection. These include ultrasonic sensors (Gunderson, Smith and Abbott, 1996), vision, GPS and GIS (Mori and Kotani, 1998) and the MANUS manipulator (ten Kate et al., 2000).

3. DISABILITIES

3.1 Visual impairment

Given that 'virtual reality' has, since its earliest development, concentrated primarily on the presentation of a high fidelity visual experience, it is perhaps surprising that the largest single group of users mentioned in the ICDVRAT proceedings are those with visual impairment.

An early proposal for use of virtual reality and associated technologies for users with visual impairment was the screen enlarger software with HMD delivery (Zwern and Goodrich, 1996). A variety of applications for this technology for blind users was proposed (Cooper and Taylor, 1998) and many papers describe application of tactile feedback technology (described earlier in §2.5) to enable visually impaired users to explore 3D data. Early studies demonstrated the potential (Jansson, 1998) as well as the problems (Colwell et al., 1998) and improved design resulted in successful perception of textures using haptic interfaces (Petrie et al., 2000). Tactile information can be enhanced by auditory and visual information although it was found that pictorial information must be simplified for haptic reading (Jansson, 2000). Consideration must also be given to ensure that the data exploration software does not in itself place increase memory demands upon the user, such as the need to remember 'beacons' marking points of interest in numerical data (Wall and Brewster, 2004).

Acoustic virtual environments have been used for spatial mapping and navigation. After several years of early development (Lumbreras and Sánchez, 1998; Berka and Slavik, 1998; Lahav and Mioduser, 2000-2), later studies found that, after exploring in virtual environments, children then explored a real environment more quickly and confidently (Sanchez et al., 2000; Lahav and Mioduser, 2004; Feintuch et al., 2004), indicating that they had been able to construct a mental model of the environment. Other research found that multimodal interaction, combining haptic and auditory information, enhanced access to 3D computer images (Gladstone, Graupp and Avizzano, 2002) and could be used for internet navigation (Caffrey and McCrindle, 2004).

The impact of acoustic-virtual environment exploration on cognitive learning for children with visual impairment has also been examined. Sánchez and Lumbreras (2000) found that learning mental structure through sound is possible and that sighted children do not use the same learning method as visually impaired children. Further study demonstrated that blind children could construct mental images of 3D space, and showed evidence of improvement in haptic perception, abstract memory, and spatial abstraction (Sánchez, 2004). Involving blind children in design of an audio-based interactive interface for learning and cognition of maths concepts was successful; the AudioMath programme resulted in memory and knowledge improvement and the system was highly accepted by users (Sánchez and Flores, 2004).

3.2 Cognitive Impairment

Several research groups have examined potential use of virtual environments for assessment and rehabilitation of patients with acquired cognitive disability due to stroke or brain injury.

Pugnetti et al. (1996) examined nervous system correlates of the virtual reality experience and found that it was possible to monitor electrophysiological brain activity whilst using VR. Other studies have also found that physiological measures can be used to assess patient responses to virtual environments (Meehan et al., 2000; Herbelin et al., 2004). Experimental studies demonstrated effective assessment of aspects of spatial memory in patients with neurological impairment (Pugnetti et al., 1998, 2000) and studies with healthy undergraduate students demonstrated superior recall of spatial layout when subjects were engaged in active participation and superior object memory in passive participation (Attree et al., 1996). Comparison of performance in virtual environment versus real world prospective memory tasks between stroke patients and healthy matched adults identified memory impairment in the stroke patients (Brooks et al., 2002). This method was successfully applied to the assessment of executive functioning, including prospective memory, in patients with prefrontal lesions (Morris et al., 2002a). Studies using immersive virtual environments were also found to show clear spatial memory deficit in patients with right temporal lobectomy (Morris, Parslow and Reece, 2000) and allocentric spatial memory in patients with anoxic hippocampal damage (Morris et al., 2002b).

3.3 Motor impairment

Research for this group generally falls into two categories: development of interaction methods providing users with access to computers (detailed in §4.1), or use of virtual reality and associated technologies for assessment or rehabilitation of motor control.

An early concept demonstration of the use of blue screen technology to provide patients with a video image of themselves on a television screen interacting with virtual objects in a video game was presented by Joyce and Phalangas (1998). This concept was extended to large project screen for gross motor rehabilitation of patients with stroke, spinal cord injury and cerebral palsy. Pilot studies using the Vivid system were encouraging, with evidence of user involvement in the VE and increased mobility (Kizony et al., 2002) and a later experimental study with stroke patients established measures of presence and perceived exertion (Kizony, Katz and Weiss, 2004). Further study compared use of the VividGroup's Gesture Xtreme (GX) system with a Sony PlayStation II EyeToy (Rand, Kizony and Weiss, 2004). Elderly patients preferred the EyeToy system. However, although the EyeToy offers considerable cost advantage over the GX system, the software games are not written for this purpose and therefore offer limitations for rehabilitation.

A similar theme has been followed by Smyth and Wann (2000) in the use of low cost interactive interfaces for movement rehabilitation. Using off-the-shelf force feedback joysticks, such as Microsoft Sidewinder or the Logitech Wingman, to develop simple navigation tasks for reinforcement learning in patients suffering from stroke. Limitations of motion provided by joysticks motivated alternative solutions such as those provided in Louriero, Collin and Harwin (2004) who have augmented the interaction with the virtual task through the provision of a large reach robot to give robot assisted motion therapy.

VRAT has been applied to rehabilitation of fine motor control (Crosbie et al., 2004). Wearing a data glove, patients performed hand movement tasks involving wrist extension and reach and retrieve tasks with visual feedback of performance provided by the VE. Results were generally favourable and patients did report experiencing fatigue and exertion, reflecting the increase in motor activity demanded by the tasks.

3.4 Learning disability

Virtual environments providing task-based training and education in everyday living or vocational skills were proposed in 1996 (Brown and Stewart, 1996). Successful transfer of learning from use of a virtual supermarket to the real world was demonstrated (Cromby et al., 1996) and transfer of learning and increased engagement in the task was found following virtual environment training in travel, shopping and ordering food in a café (Cobb, Neale and Reynolds, 1988). Evidence of transfer of training was also found following virtual environment training in kitchen skills for students with learning disabilities attending a catering college (Rose et al., 1998; Rose, Brooks and Attree, 2000) and the VIRT factory trainer project developed a commercially available training package for users with learning difficulties seeking employment in sheltered factories (Mendozzi et al., 2000). Whilst successful transfer of training was demonstrated in these projects, it was suggested that virtual environment training is not *better than* other training methods for these users (Rose, Brooks and Attree, 2000). Furthermore, other studies have found that students require tutor instruction to guide them through virtual environment interaction (Standen and Low, 1996; Standen et al., 2000) and that the virtual reality training module should be incorporated as part of a larger training programme (Shopland et al., 2004).

Some studies have specifically examined user control over virtual environment interaction finding that, with tutors proving support ('scaffolding'), students do progressively make more self-initiated actions and therefore gradually increase self-directed learning (Standen and Low, 1996). Studies examining use of interaction devices found that dual control devices are confusing for users with learning difficulties and that it is better to separate control-action by using a joystick for navigation and mouse for interaction selection (Lannen, Brown and Powell, 2000; Lannen, Brown and Standen, 2002; Standen et al., 2004).

A feature of learning disabilities research in ICDVRAT has been user involvement in design of VEs and interaction methods. User-centred design methodology applied in the Virtual City Project (Brown, Kerr and Bayon, 1998) included a user group of 10 students from the Shepherd School in Nottingham who were directly involved in making design decisions during interactive VE development. The entire user group attended the second ECDVRAT conference to present their involvement in the project and their view of this kind of participatory design (Meakin et al., 1998). Subsequent projects have applied this methodology specifically for design development of interaction devices (Lannen, Brown and Standen, 2002; Brown, Shopland and Lewis, 2002; Anderton, Standen and Avory, 2004; Battersby et al., 2004).

3.5 Wheelchair users

Virtual reality and associated technologies have been developed to provide assistive control and training of wheelchair control. Gunderson, Smith and Abbott (1996) presented a concept realisation of a combined human-control/autonomous control system supported by sensor control for collision avoidance. Peussa, Virtanen and Johansson (1998) demonstrated a prototype system using ultrasonic range sensors. Desbonnet, Cox and Rahman (1998) explored use of VE modelling for wheelchair control training. At this stage the application was limited due to low levels of visual realism and crude software modelling. The system was improved and tested with children. These studies found that the nature of disability affected usability of the VE Mobility Simulator (VEMS) (Adelola, Cox and Rahman, 2002) and other tests of virtual environments for training wheelchair control found that manoeuvrability was harder in the virtual environment than in the real world (Harrison et al., 2000). It is concluded that care must be taken ensure that these training simulators are suitable for individual training needs and purpose.

4. APPLICATIONS

4.1 Access and interaction

A considerable amount of ICDVRAT research has examined access and interaction methods – either to provide access to computers for users for whom traditional interface methods are not appropriate, or to develop new interaction methods required by new 3D multimedia environments. Access and interaction methods described include:

- Body movement (camera tracking of user movement) (Madritsch, 1996; Foyle and McCrindle, 2004)
- Mouse emulation: Head controlled mouse emulator for interaction with virtual keyboard (Coyle et al., 1998). Gaze controlled interaction with virtual keyboard (Istance, Spinner and Howarth, 1996). Use of force-feedback mouse with software to detect and compensate for uncontrolled movement such as spasm (Langdon et al., 2002).
- Interaction with virtual agents: navigation using speech, behaviour and gaze (Nijholt et al., 2000).
- Tactile access to 3D graphical information and aural exploration of 3D environments for users with visual impairment (described in §3.1).
- Software adaptation to support multi-modal activity in Windows (Glinert and Wise, 1996; McCrindle and Adams, 1998; Haverty, 2004).
- Use of devices for VE navigation and interaction by people with LD (described in §3.6)
- Successful development of sonar in 3D VE games such as audio space invaders (McCrindle and Symons, 2000) and the Terraformers real-time 3D game with sound interface (Westin, 2004).

4.2 Training and education

Virtual environments for education have been applied to children with intellectual and learning disabilities (described in §3.6) and cognitive development of children with visual impairment (described in §3.1). They have also been applied to evaluation and training of spatial awareness in children with physical disabilities. Stanton, Wilson and Foreman (1996) found 3D training to be better than 2D training for navigational spatial task performance and evidence of transfer of training (of spatial skill) from one VE to another (Stanton et al., 2000) although it could not be determined how much of this was due to features of virtual environment rather than any form of training. These researchers found evidence of vertical asymmetry in spatial memory, in which downward spatial judgements were more accurate than upward spatial judgement, presenting implications for design and use of multi-level VEs for training (Stanton et al., 2002).

A number of research groups have examined use of virtual environments for travel training. A virtual environment for safe street crossing has been tested with stroke patients (Naveh, Katz and Weiss, 2000; Katz et al., 2004) and found that virtual environment intervention was effective in improving measures of visuo-spatial tests and post-VE real world performance in road crossing. A 2D virtual reality street crossing simulation pilot tested with stroke patients found that subjects found it easy to use but requested much more content in the visual scene and additional tasks to do (Lam et al., 2004). An interesting observation from this study was that subjects preferred a 3rd person view of the avatar. Preference for the 3rd person avatar viewpoint was also found in similar research investigating use of 3D virtual environments for travel training of individuals with learning disabilities (Shopland et al., 2004). More recently, virtual environments have been applied to support training of individuals with travel phobia (Sik Lányi et al., 2004).

It has been considered that virtual environments may provide an ideal medium for training for individuals with autistic spectrum disorders (ASD), although consideration must be given to content, design and layout of the virtual environments for this user group (Charitos et al. 2000; Dautenhahn, 2000; Parsons et al., 2000). Later experimental studies found that virtual environments could be used to support training of appropriate social behaviour within one context, although students could not generalise their learning to a different social context (Leonard, Mitchell and Parsons, 2002). This research concluded that virtual environments could successfully be used for education and training but not in isolation. The virtual environment should be regarded as a teaching tool, and is best facilitated by educators (Neale et al., 2002).

4.3 Assessment and rehabilitation

Extensive research has examined use of virtual reality for assessment and rehabilitation of cognitive function. The ImmersaDesk system was used to assess cognitive and functional impairment in patients with traumatic brain injury (TBI), neurological disorder and learning disabilities. Development of a VE-delivered neurological test battery incorporating mental-rotation and reaction time tasks, memory assessment, measures of target acquisition and target recall have been presented by Rizzo et al. (1998, 2000, 2002, 2004). Findings have demonstrated potential as a cost-effective, scaleable tool for attention performance measurement (Rizzo et al., 2002). Others have described development and application of virtual environments for rehabilitation of executive function skills (da Costa et al., 2000; Lo Priore, Castelnuovo and Liccione, 2002).

It has been suggested that virtual reality could be used for postural assessment and vestibular rehabilitation (Alpini et al., 1998; 2000). Use of a computerised system to present bio-feedback of patient centre of pressure in neurological patients found positive, but not conclusive, results with patients with multiple sclerosis (Cattaneo and Cardini, 2000). They concluded that virtual reality could provide a reliable data collection method but needed further developing. A study by Keshner et al. (2004) used projection-based virtual environments, with CrystalEyes shutter glasses to immerse patients in the virtual environment. They measured postural responses to motion of the visual field (sled or scene motion) and found different results for young compared with old adults. Nyberg et al. (2004) found that elderly subjects walked more slowly when immersed in a VE using a HMD and that balance control was most affected by tilting of the visual scene.

Virtual environments have been developed for rehabilitative rehearsal of everyday activities. The Virtual Kitchen provided a number of activities focused around a virtual coffee-making task. Initial pilot studies with Occupational Therapists and patients with traumatic brain injury (TBI) identified design and interface issues (Davies et al., 1998) and recommendations for use of click and drag interaction metaphor and automatic navigation control for users with TBI (Lindén et al., 2000). Case studies of patients using the virtual kitchen and a virtual ATM (automatic teller machine) suggested that virtual reality could be a valuable training tool for patients with TBI, although concern was raised that the development of training environments may not be cost-effective (Davies et al., 2002). Recommendations were proposed for a modular approach to virtual environment construction that would allow for re-use of generic components of a virtual activity (Wallergard et al., 2002).

A virtual kitchen and hot drink-making task was also developed for stroke rehabilitation (Hilton, Cobb and Pridmore, 2000). In an attempt to support rehabilitation of functional performance of this task in addition to cognitive aspects, a tangible user interface was developed allowing direct manipulation of real objects to control the virtual task (Hilton et al., 2002). Lack of flexibility of a tethered interface design led to early stage development of a mixed-reality interface using camera vision to monitor user selection and movement of real objects (Pridmore et al., 2004). However, a clinical pilot study identified limitations of the virtual environment task for rehabilitation of cognitive skills, suggesting that it may *increase* cognitive demand and offer no benefit over supervised real world rehearsal (Edmans et al., 2004).

Greater success appears to have resulted from use of virtual environments for rehabilitation of motor control and coordination of stroke patients. An early demonstration of the potential use of VR technology for rehabilitation of patients with brain injury was the exercise bike used to control navigation (Johnson, Rushton and Shaw, 1996).

Sonic movement environments use auditory feedback as a motivation for patient movement. Tarnanas and Kikis (2002) compared visual feedback with auditory feedback and no feedback for children with learning disabilities. The study found auditory feedback did help with developments in kinaesthesia, motor planning, sequencing and timing capabilities. Lewis-Brooks and Hasselblad (2004) demonstrated potential for use of aesthetic resonant environments as an effective medium providing interactive therapeutic exercises to encourage body awareness, co-ordination and movement in children with physical and cognitive disability. A conceptual model for use of Soundscapes for home-internet based rehabilitation for stroke patients was also presented (Lewis-Brooks, 2004).

4.4 Mobility aids

Virtual reality and associated technologies have been applied to enhancing mobility via the development of mobility aids. Much of this research is technology development and includes: sensors mounted onto wheelchair to facilitate obstacle detection and avoidance (Probert, Lee and Kao, 1996); use of wheelchair-mounted sensors and VR technology for remote control over wheelchair (Gunderson, Smith and Abbott, 1996; Peussa, Virtanen and Johansson, 1998); integration with VR to provide salient information to user (Everingham et al., 1998) and for simulated training of wheelchair use (Desbonnet, Cox and Rahman, 1998; Niniss and Nadif, 2000); intelligent systems providing visually impaired users with information of the hazards around them – the Robotics Travel Aid (RoTA) (Mori and Katani, 1998; Mori et al., 2002) and the Pedestrian Intelligent Transportation System (P-ITS) (Sasaki et al., 2000; Kuroda et al., 2002).

4.5 Language and communication

Virtual reality and associated technologies have also been applied to support of language development and communication for users with speech and/or hearing impairment. Much of this research has been on development and testing of software algorithms to recognise sign language (Losson and Vannobel, 1998; Kuroda et al., 2004) for conversion to speech (Vamplew, 1996) or for animated representation of sign to be used for training people recognise sign language (Tabata et al., 2000; Papadogiorgaki et al., 2004).

However, the work of Sawada's group has shown that technology can also be used to good effect in the areas of improvement of speech synthesis techniques for oesophageal speech (Hisada and Sawada, 2002; Sawada, Takeuchi and Hisada, 2004), whilst others have developed systems for speech therapy: for example Vicsi and Váry (2002) studies in language teaching and training support showed the effectiveness of using visual feedback to help with pronunciation.

4.6 Technology for professional use

Virtual networks have been proposed as an aid for therapists (Magnusson, 1996; Magnusson, 2000; Teittinen and Väätäinen, 2000), collaborative networks between therapists and patients (Almeida and Ramos, 2000; Olsson, Carignan and Tang, 2004), simulation training to enable caregivers to experience stroke (Maxhall et al., 2004) and for medical simulation: knee surgery (Hollands and Trowbridge, 1996) and for surgical training (Al-khalifah and Roberts, 2004).

4.7 Virtual environments as design tools

Early consideration of virtual reality suggested that it may be an ideal medium for evaluation of adaptations made to the home or workplace for disabled users. A prototype system demonstrated potential for integration of computer-aided design models to allow for visualisation of design and user walkthrough of the adapted environment (Davies and Eriksson, 1996). A motion platform integrated with a virtual reality demonstrator system was used to evaluate buildings and environments designed for wheelchair users (Harrison et al., 2000). The HabiTest 3D environment builder demonstrated in 2004 was evaluated by people with physical disabilities with positive results from user testing (Palmon et al., 2004). Virtual environment modelling has also been applied to testing of rehabilitation aids by incorporating anthropometric human models into the VE design (Beitler and Foulds, 1998) or by allowing users themselves to view and evaluate rehabilitation products (Nichols et al., 2002). This latter study found that the VE model was acceptable to elderly patients and could be used to evaluate products, although they did not make use of all of the features of the virtual environment system (zooming, alternative viewpoints, etc.).

5. PROMISE OR PRACTICE – HOW FAR HAVE WE PROGRESSED?

The first ECDVRAT offered suggestions for, and early demonstration of, potential applications of virtual reality and associated technologies for disability. Inter-mingled with expectations for technologies to enhance and improve quality of life, concerns were also raised that we should not throw technology at this community as a 'solution looking for a problem' (Wann, 1996), and that we should ensure that the technology itself did not present users with adverse experiences, including side effects of VR-immersion (Rose, 1996; Zwern and Goodrich, 1996).

Ten years on, we know that these concerns were not barriers to effective implementation of technology for disability. Studies found that side effects were mild and transient in stroke patients (Crosbie et al., 2004) and patients with neurological impairment were at no higher risk of experiencing these symptoms than healthy subjects (Pugnetti et al., 1998). No side effects have been reported in use of non-immersive systems.

Virtual Reality and Associated Technologies are a range of technologies offering interfacing to, and interaction with, multi-media computers, virtual and real environments. They comprise: an 'environment' which can be anything from real world, through networked real world (telecommunication), 'mixed reality' environments, to non-immersive simulated VE, and fully-immersive VE; interaction with computers using devices such as joystick, mouse, 3D controller, gesture and body movement, gaze, and haptic interfaces; feedback from computers via visual, audio, tactile or force-feedback sensory channels; sensor technology such as motion tracking, ultrasound and camera vision; real-time software filtering to compensate for, or enhance feedback to, users with specific interaction and/or sensory requirements.

During this first decade of research, application ideas and potential uses of VRAT have included:

- Rehabilitation following traumatic brain injury (Rose, 1996)
- A means of providing access to computers for visually impaired users (Zwern and Goodrich, 1996)
- A virtual meeting place for representation of emotion (Roberts, Wood and Gibbens, 1996)
- Music therapy (Swingler, 1998)
- Creation of perceptual worlds representing 'inner landscapes' to enhance cognitive learning for visually impaired (Sánchez, Barreiro and Maojo, 2000).
- Interactive painting – movement controlled sound and graphic display (Lewis-Brooks, 2004)
- Rehabilitation that can be offered at home (Loureiro, Collin and Harwin, 2004)

Some of the early promise of this technology is finding its way into practice. Successful application has been demonstrated in use for neurological assessment and in provision of access to computer environments for visually impaired users. Some evidence also indicates realisation of potential for VRAT in rehabilitation of motor control and cognitive skills development.

In many cases, research has not yet reached the stage at which evidence in practice can be demonstrated. In part, this is due to the fact that many projects require years of technical development and pilot testing before they reach experimental testing with target end users. A considerable amount of research effort has contributed to design, development and evaluation of these technologies and some projects have involved large research collaborations between academics, practitioners and users from several different countries.

New areas of application are also emerging, such as home-based rehabilitation systems, pain distraction and exposure therapy. Predominant use of low-cost desktop delivery systems and integration with other technology (for accessibility or assessment of disability) will ensure that the high end and, perhaps, more blue skies approach of some programmes reported through the pages of these Proceedings will find their way into real world solutions for real world problems.

6. CONCLUDING REMARKS

Developing this review of a decade of research and development in disability, virtual reality and associated technologies, raised a number of issues and problems – not least, how to represent in a reasonably concise way the breadth and depth of research in the general area, and also how to structure the contributions. The multidisciplinary nature of the whole research area presents multi-dimensional threads that bind disparate application areas using similar technology or disparate technological solutions applied to the same application area. What has become clear over the past decade is that, as the years have progressed, the ICDVRAT community has developed an impressive body of evidence that virtual reality can and does provide mature alternative solutions. The *esprit de corps* that is so evident in the community bodes well for future collaboration.

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7. REFERENCES

All papers are from the conference proceedings and can be found online at the conference archive: www.icdvrat.reading.ac.uk. For brevity, papers cited in this paper will be referred to below by authorship, paper title and year of publication as follows:

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