

Virtual vestibular re-education. A new technology.

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Abstract. *Virtual vestibular re-education. A new technology.* This paper will provide an introduction to the use of virtual environments for vestibular re-education.

The author illustrates some of the ways in which researchers are using virtual reality to improve therapy for vertigo. Users of virtual reality must make adaptations to avoid mismatches between perception due to virtual reality and that due to vestibular and proprioceptive subsystems.

Virtual reality may be an interesting new way of studying vestibular compensation in normal and pathological conditions.

Introduction

Virtual environments are usually created using special hardware and software for input (transfer of information from the user to the system) and output (transfer of information from the system to the user). The selection of appropriate hardware and software is important because their characteristics may greatly influence the way users respond to a virtual environment. The output to the user can be delivered in different modalities, including visual, auditory, vestibular, and olfactory stimuli. However, to date, most Virtual Reality (VR) systems primarily deliver visual-auditory feedback. Visual information is commonly displayed using head-mounted displays, projection systems, or flat screens of varying size. Application software is needed alongside specialised hardware. In recent years, off-the-shelf, ready-for-clinical-use VR software has become available for purchase.

However, more frequently, special software development tools are required for the design and coding of an interactive simulated environment that will achieve a desired rehabilitation goal. In many cases, innovative intervention ideas may entail customised programming for the construction of a virtual environment from scratch using traditional programming languages.¹

State of the art

Viiirre² discusses the use of VR technologies in the rehabilitation of patients with vestibular disorders and in the provision of remote medical consultations for those patients.

Alpini *et al.*³ have proposed using virtual environments of increasing complexity in terms of directional and topographic information, allowing for navigation through the active control of the subject's own centre of gravity.

This system has been designed for both diagnostic use and therapeutic training, and essentially consists of the integration of three different hardware subsystems: an immersive VR server, a digital craniocorpography unit and a stabilometric platform.

The signals from the stabilometric platform with the user in standing position are used to control movement inside the virtual environment.

In addition, the craniocorpography unit allows for the monitoring of the head-and-shoulder displacement strategy during hip displacements used to modify the projection of the centre of mass in response to virtual visual/acoustic stimuli.

The combination of these instruments improves sensory-motor learning on the basis of feedback in ways similar to classic vestibular rehabilitation protocols. With the system based on virtual reality, it is possible to achieve a better integration of cognitive

factors used to enhance more conscious equilibrium control.

Kramer *et al.*⁴ have developed a versatile, low-cost, stereoscopic visual display system using VR. They elicited smooth pursuit, "stare" optokinetic nystagmus (OKN) and after-nystagmus (OKAN) vergence for targets at various distances, and short-term adaptation of the vestibulo-ocular reflex (VOR) using both conventional methods and a stereoscopic display. Pursuit, OKN and OKAN were comparable with both methods.

When using a vestibular stimulus, VR induced appropriate adaptive changes of angular VOR phase and gain. In addition, the VR display system and a human linear acceleration sled were used to adapt linear VOR phase.

The VR-based stimulus system not only offers an alternative to more cumbersome ways of stimulating the visual system in vestibular experiments. It can also produce visual stimuli that would otherwise be impractical or impossible. Its techniques provide images without the latencies encountered in most VR systems. Its inherent versatility allows it to be useful in several different types of experiments and, because it is software-driven, it can be adapted quickly to provide a new stimulus.

These two factors allow VR to provide considerable savings in time and money, as well as flexibility in the development of experimental paradigms.

Di Girolamo *et al.*⁵ studied post-immersion modifications in 20 healthy subjects (mean age 25 years) exposed to a virtual environment for 20 minutes using a head-mounted display.

VOR gain and phase were measured by means of harmonic sinu-

soidal stimulation in the dark before, at the end of, and 30 minutes after, VR exposure. A VOR gain reduction was observed in all subjects at the end of VR exposure, disappearing after 30 minutes. The data from this study show that exposure to a virtual environment can induce a temporary modification of the VOR gain. This finding can be used to achieve an artificial, instrumental modification of VOR gain. It therefore opens up new perspectives for the assessment and rehabilitation of vestibular diseases.

The aim of the study of Lott *et al.*⁶ was to determine whether different limitations of the centre of pressure (COP) movement occur when different approaches to delivering virtual environments are used and when visual information incoherent with vestibular and somatosensory information is provided. Eighteen healthy adults made voluntary lateral reaches under three conditions: continuous lateral reach (CLR), flat screen virtual reality (FS), and head-mounted display virtual reality (HMD). Reaching behaviour was indexed using force-plate measures of maximum anterior-posterior and lateral displacement of the COP. COP movement decreased in the lateral direction in the HMD condition relative to the FS. The maximum range of COP movement in the anterior-posterior direction increased as a function of the reaching task, with the greatest amount of movement being found in the HMD condition. The lack of an exocentric frame of reference in HMD that is coherent with information from other sensory systems limits COP movement within the base of support (BOS) in order to decrease

the challenge to the postural control system.

Cesarani and Alpini⁷ describe virtual reality as a new technology that modifies the way individuals interact with computers. It consists of a set of computer-aided technologies that, when combined, provide an interface with a computer-generated world. In particular, it provides such a convincing interface that users believe they are actually in a three-dimensional environment and so they can navigate and interact with this virtual world in real time.

The benefits and prospects associated with this technology from the Mechanic Cybernetic Synergetic (MCS) point of view are:

- A. improvement of spatial knowledge, i.e. spatial orientation and spatial exploration;
- B. simulation of potentially dangerous situations;
- C. training postural control in an artificial environment.

Spatial knowledge is organised at three levels:

1. memorising main landmarks;
2. the integration of these landmarks inside pathways or sensory motor sequences;
3. the processing of a panoramic landscape representation in which both landmarks and pathways interact.

The vestibular system is involved in the representation of spatial knowledge, not only to assure postural control and visual stabilisation but also to establish the directional context and to calculate the best paths linking the memorised places on the basis of visual landmarks.

Knowledge of an unknown environment is easier if active

exploration rather than mere observation of the places on paper is possible. Many authors in controlled experimental conditions have also stated that virtual environment and virtual navigation can improve spatial orientation.

Since virtual reality can manipulate the perception of the spatial features of visual input, it is possible to develop exercises for equilibrium control training in static and dynamic conditions. For instance, in 1998, Jaffe⁸ proposed a programme intended to prevent falls in the elderly based on the evaluation of postural control and on equilibrium training using virtual obstacles and simulating potentially dangerous situations.

Akizuki *et al.*⁹ examined the effects of the time lag between the visual scene and head movement in the virtual reality (VR) world on motion sickness and postural control in healthy volunteers. After immersion in VR with additional time lags (from 0 to 0.8 s) to the inherent delay (about 250 ms), the visual-vestibular conflict induced mild motion sickness in experimental subjects but no change was noticed in the body sway path with eyes open and closed. However, the Romberg ratio of body sway path with eyes closed divided by that with eyes open after immersion in VR was significantly decreased compared to the ratio before immersion in VR. Since the Romberg ratio is an index of visual dependency on postural control, this finding indicates that the immersion in VR reduces visual dependency on postural control. It is suggested that adaptation to visual-vestibular conflict in VR immersion increases the contribution of vestibular and somatosensory inputs to postural control by ignoring the conflicting

delayed visual input in the VR world. VR may be a promising treatment for visual vertigo in vestibular patients with unsuccessful compensation because it allows for the induction of vestibular and somatosensory reweighing for postural control.

Further information may be found on the site www.cybertherapy.info,¹ mainly in a text from Stoffregen *et al.*¹⁰ about "Vestibular adaptation and after-effects measurement".

Discussion

It is important to emphasise that, even now, the most powerful and fastest computers are unable to recreate exactly all natural and real environments. Users of virtual reality must therefore adapt in response to what they experience.

The main problems that may arise are:

- mismatch between motor perception produced by the visual virtual environment and that due to vestibular or proprioceptive subsystems (visual-inertial mismatch);
- intra-vestibular mismatch between semicircular canal and otolithic inputs.

In these cases, oscillopsia and "cybersickness" may develop: the symptoms are similar to "car sickness" or "sea sickness".

It should be pointed out that:

- cybersickness indicates exceedance of compensation ability. There is overcompensation through hyperstimulation;
- generally, there is an adaptation to the new situation in order to reduce symptoms;
- a memory of this adaptation persists in time.

Conclusion

Virtual reality limits may be an interesting means of studying vestibular compensation in normal and pathological conditions.

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