UTILIZATION OF VIRTUAL REALITY TECHNOLOGY IN THE REHABILITATION OF BALANCE DISORDER PATIENTS

By
Dr. Erik Viirre
Jim Buskirk

Abstract

Lesions of the vestibular organ lead to complaints of unstable vision, dizziness and imbalance. Such lesions are also accompanied by abnormalities on vestibular function testing: specifically the vestibulo-ocular reflex (VOR) is altered, usually resulting in abnormal ENG caloric responses and abnormal results with rotary chair testing.

Posturography measurements and measurements of static and dynamic balance functionally are often altered. The VOR is a vision-stabilizing reflex. In it, signals from the vestibular apparatus drive movements of the eyes to keep the visual world stable as the head moves. We know that small lesions of the vestibular apparatus lead to changes in the VOR. Specifically, the gain of the VOR (defined as the magnitude of the eye velocity output divided by the head velocity stimulus) may be altered. There is a neural mechanism that adapts to changes in VOR gain. Small defects in VOR gain, such as when a new spectacle prescription is worn are rapidly corrected. However, with large changes in VOR gain, such as when the vestibular apparatus input from one ear is surgically removed, the adaptive mechanism appears to fail. Such patients usually have chronically low VOR gains and persistent sensations of vertigo and imbalance.

There are two theoretic possibilities: the lesion could have ablated the adaptive mechanism as the VOR was disrupted, or the adaptive mechanism may have been overwhelmed by the magnitude of the lesion. The latter appears to be the case. We have tested patients with persistently altered VOR gains and have found that it is possible to slightly alter these gain values temporarily with a new method of adaptation, utilizing Virtual Reality. We have developed an immersive interactive computer graphics environment designed for visual-vestibular interaction research. A subject wears a head-mounted display that provides a wide image and blocks the view of the outside world. As the subject moves, a head position and orientation tracker measures the position of the head. The computer rendering system then shifts the scene to correspond to the new point of view. In the graphics environment the magnitude of visual scene movement relative to head movement and rate of optic flow is under software control.

Our protocol for adaptation uses the computer control and uses the observation that small-required changes in VOR gain are rapidly adapted to. Thus if a subject had a VOR gain of 0.4, we demagnified the scene to 0.44, thus requiring an adaptation of 10% instead of 250% 30 minutes of exposure increased to successively larger increments in this paradigm produced significant VOR gain changes at 0.32 and 0.64 Hz measured by rotary chair, and at 0.5 and 1.00 Hz using VORTEQ measures immediately after the exposure. In the work proposed here, we will test subjects after repeated exposures to successive increments in required VOR gain and determine if we can induce a persistent VOR gain change and a reduction of symptoms.

Introduction

Stabilization of an object's image on the retina of the eye during active or passive head motion is necessary to avoid "slippage" of the image, giving rise to the perception of oscillopsia or impaired visual acuity. This stabilization of the image is a function of the VOR. It can be hypothesized that a "learning" process occurs during development of this system from birth, in which frequencies of head motions are responded to by both concentric and eccentric eye motions controlled by Cranial nerves III, IV & VI. This learned process can be termed the visual-vestibular interaction (VVI). Any outside negative influences to this interaction will cause a perception of dizziness, and further, a development of imbalance if the efferent motor preprogramming (also a "learned" process) is also affected. Simply stated, "the motor output doesn't match the expected predetermined plan."

As with most central neural processes, there exists a surplus of ability to learn such processes Only a part of the system's capacity is utilized, the remainder being unused, and in reserve with compensatory capabilities. When the system is functioning normally, there is a baseline firing rate of the peripheral vestibular apparatus being processed centrally. There is then an efferent motor response via the postural stabilizing system. If the visual-vestibular interaction is not functioning normally, the compensatory mechanisms are called upon to act to stabilize the person's vision and equilibrium posturally. If the system continues to function abnormally for an extended period of time, the abnormal becomes the norm for the person, and a new learning mechanism begins. If the person has limited compensatory capabilities, the vision remains unstable while the head is in motion (oscillopsia), and the person's balance is impaired.

The difference between the amounts of afferent input between the two sides determines the extent of the symptoms and functional performance loss. This can be related as well to a change in VOR gain. Therapeutic treatments for gaze stabilization and postural control can be helpful in most cases. Medications which act centrally may be beneficial as well, as they act to narrow the difference between the afferent inputs by the two sides. However, the secondary actions of these medications may prohibit their use, and they may also lengthen the compensatory recovery time. Therefore, the modality of Virtual Reality in incremental sessions of exposure may be beneficial in modifying VOR function and lessening the use of suppressive medications.

Research Protocol

The research protocol is being carried out at the University of California, San Diego with Dr. Erik Viirre as the Principal Investigator. The project is being funded by the National Institute of Deafness and Communication Disorders in Project #RO3DC03507. A similar protocol is being conducted at Balance Centers of America in Wilmette, IL and Merrillville, IN with Jim Buskirk as the Principal Investigator and Dr. Viirre as co-investigator. Data is also being collected in San Diego, CA under the direction of Dr. Erik Viirre and at the Naval Medical Center at San Diego (NMCSD) in the Department of Otolaryngology.

While in the research protocol, no additional "traditional" forms of vestibular therapies are performed. After completing an informed consent, two questionnaires are completed: the Jacobson Dizziness Inventory and the Activities-specific Balance Confidence (ABC) Scale. In IL and IN, a measure of the person's VOR gain is obtained, using VORTEQ testing at 0.5 and 1.0 Hz frequencies. These are done with active and passive head motions. In addition, a measure of the person's dynamic visual acuity is taken, using the Dynamic Visual Acuity Test (DVAT) from Micromedical Technologies. A measure of the person's posture is also taken with the Neurocom Equitest and SMART BalanceMaster equipment, both with and without utilizing the "head tilt" protocol.

In San Diego, the VOR gain value is measured using the System 2000 rotational chair. Then, the Virtual Reality (VR) protocol is instituted, either to raise or lower the gain value. The VR protocol takes place over 5 successive days, with 30-minute sessions each day. At 10-minute intervals, the person's symptoms are measured at 0-3 severity to avoid the phenomenon of "simulator sickness". In San Diego, daily VOR gain values are taken, while in IL and IN the gain values are obtained every other day if able, and at minimum, at the end of the fifth day's VR session. For some subjects, daily measures are taken in IN and IL, while in San Diego, only every other measures are taken for comparison. Since subjects with VOR gain values higher than normal usually have more severe symptoms, smaller successive increments of VR magnifications are utilized than for the subjects who have lower than normal gain values. Magnification rates are changed by 10% when lowering gain values, while a 15% change is used when attempting to raise gain values. The two questionnaires are repeated at the end of the fifth session. Follow-up questionnaires are completed one week after the last session, and again one month later. For those subjects who can return, VOR gain values, dynamic visual acuity scores, and balance and posturography scores are repeated at one week and one month following the last VR session.

Results

A pilot study of 6 subjects was conducted prior to instituting the full research protocol. Five of the six subjects were able to avoid usage of any suppressive medications. Four of the six subjects reported decreased symptoms of dizziness and imbalance, with improved performance functionally. One reported no change and one reported increased symptoms and asked not to continue with the protocol after the second session. That subject was thought to have an unstable lesion, and was returned to the Otolaryngologist for further management. The VOR gain values were improved, and when analyzed, were found to be statistically significant. At the time of this writing, efforts are being made to analyze 100 subjects at each facility for data collection. This will lead to further investigation of this tool as a viable method of aiding in the rehabilitation of people with complaints of dizziness and imbalance with measured abnormal VOR gain values, abnormal dynamic visual acuity scores, and abnormal measures of posture and equilibrium.

References

1. Black FO, Brackmann DE, Hitselberger WE, Purdy J. Preservation of auditory and vestibular function after surgical removal of bilateral vestibular schwannomas in a patient with neurofibromatosis type 2. Am J Otol 1995; 16:431-43.
2. Herdman SJ, Clendaniel RA, Mattox DE, Holliday MJ, Niparko JK. Vestibular adaptation exercises and recovery: acute stage after acoustic neuroma resection. Otolaryngol Head Neck Surg 1995; 113:77-87.
3. Konrad HR, Tomlinson D, Stockwell CW, et al. Rehabilitation therapy for patients with disequilibrium and balance disorders. Otolaryngol Head Neck Surg 1992; 107:105-8.
4. Robinson DA. Adaptive gain control of vestibulo-ocular reflex by the cerebellum. J Neurophysiol 1976; 39:954-69.
5. Robinson DA. Control of Eye Movements. In:Brookhart JM, Mount Castle VB, eds. Handbook of Physiology-section 1: The Nervous System. (Vol.2, part 2). Bethesda MD: American Physilogical Society, 1981:1275-1320.

References

6. Mellville-Jones G, Davies P. Adaptation of cat vestibulo-ocular reflex to 200 days of optically reversed vision. Brain Res 1976; 103:551-4.
7. Melville-Jones G. Plasticity in the adult vestibulo-ocular reflex arc. Philos Trans R Soc Lond B Biol Sci 1977; 278:319-34.
8. Demer JL, Goldberg J, Porter FI, Jenkins HA, Schmidt K. Visual-vestibular interaction with telescopic spectacles. J Vestib Res 1990; 1:263-77.
9. Demer JL, Viirre ES. Visual-Vestibular Interaction during standing, walking and running. J. Vestibular Research 1996; 6:295-313.
10. Collewijn H, Martins AJ, Steinman RM. Compensatory eye movements during active and passive head movements: fast adaptation to changes in visual magnification. J Physiol Lond 1983; 340:259-86.
11. Viirre E, Cadera W, Vilis T. Monocular adaptation of the asccadic system and vestibulo-ocular reflex. Invest Opthalmol Vis Sci 1988; 29:1339-47.
12. Viirre E, Cadera W, Vilis T. The pattern of changes produced in the saccadic system and vestibulo-ocular reflex by visually patching one eye. J Neurophysiol 1987; 57:92-103.
13. Viirre ES. Independent Control of the two eyes during saccades and the vestibulo-ocular reflex. Physiology. London, Canada: University of Western Ontario, 1987.
14. Viirre ES. Virtual Reality and the Vestibular Apparatus. IEEE Engineering in Medicine and Biology 1996; 15:41-43.
15. Viirre ES, Demer JL. The Vestibulo-ocular Reflex (VOR) during Horizontal Axis Eccentric Rotation and near target fixation. In: B.Cohen, Highstein S, eds. New directions in Vestibular Research. New York: New York Academy of Sciences, 1996:706-708.
16. Viirre ES, Demer JL. The vestibulo-ocular reflex during horizontal axis eccentric rotation and near target fixation. Ann N Y Cad Sci 1996;781:706-8.
17. Viirre ES, Demer JL. The human vertical vestibulo-ocular reflex during combined linear and angular acceleration with near target fixation. Exp. Brain Res. 1997:In press.
18. Viirre ES. Virtual Environments: a new technology for vestibular research. J. Vestibular Res. 1996; 6:S74.
19. Gordon CR, O.Spitzer, Dowek I, Shupak A, Gadoth N. The Vestibulo-ocular reflex and seasickness susceptibility. J. Vestibular Res. 1996;6:229-233.
20. Kramer PD, Roberts DC, Shelhamer M, Zee DS. A versatile stereoscopic visual display for vestibular and oculomotor research. J. Vestibular Res. 1997; 7:100-110.
21. Shelhamer M, Tiliket C, Roberts D, Kramer P and Zee D. Short term vestibulo-ocular reflex adaptation in humans II. Error Signals. Exp. Brain Res. 1994; 100:328-336.
22. Newman CW, Jacobson GP. Application of self-report scales in balance function handicap assessment. Seminars in Hearing 14(4):363-375.

Biographies

Dr. Erik Viirre

Dr Erik Viirre is an Assistant Adjunct Professor in the Division of Otolaryngology of the University of California, San Diego School of Medicine and a consultant for various laboratories and industries. His research and clinical interests include vision and the balance sensing system of the body, the vestibular apparatus. His clinical specialty is Vestibular Neurotology: the diagnosis and treatment of patients with vertigo and balance problems. At UCSD, Dr. Viirre is the principal investigator on a National Institute of Health research grant, studying the use of Virtual Reality technology in rehabilitating patients with balance disorders and is preparing a virtual clinic where he will see patients in remote locations using telemedicine. He has already demonstrated diagnosis and treatment of vertigo patients in remote locations.

Dr. Viirre is participating in several projects at the Human Interface Technology Laboratory of the University of Washington including vision research on the Virtual Retinal display (VRD) and studies on motion sickness in virtual environments. Dr. Viirre received his Ph.D. in neurophysiology in 1987 at the University of Western Ontario in London, Canada and M.D. in 1988 at the same institution. In 1989 he was an intern at St. Joseph's Hospital in London, Canada. He then went onto a fellowship with the Imaging Research Group of the Roberts Research Institute in London and had a medical practice delivering basic eye care. He also studied vestibular disorders in the Department of Otolaryngology-Head and Neck Surgery with Dr. Joseph McClure at the University of Western Ontario. In 1994-95, Dr. Viirre was an Assistant Visiting Professor in the Department of Neurology at the UCLA School of Medicine and in the Jules Stein Eye Research Institute at UCLA.

Jim Buskirk

Jim Buskirk, PT is a Physical Therapist in private practice, with offices throughout the Chicago, IL area, serving patients with orthopedic and neuromusculoskeletal dysfunctions as well as providing vestibular physical therapy at Balance Centers of America with offices in Wilmette, IL, and Merrillville, IN. In 1983 Jim received his degree in Physical Therapy from the University of Health Sciences/The Chicago Medical School. In 1987 he completed the Musculoskeletal tract in the graduate degree program at Northwestern University's School of Physical Therapy.
He currently serves as the team Physical Therapist for the Chicago Wolves Professional Hockey team in Chicago. For the past 2 1/2 years he has held a contract with both the Great Lakes Naval Training Center in North Chicago, IL and the Naval Medical Center at San Diego (Balboa) to provide vestibular physical therapy to active duty military personnel. He has established the Balance Therapy Research Foundation to conduct research in the areas of vestibular and balance therapies. Currently Jim is participating with Dr. Erik Viirre, Dr. Kim Gottshall, Dr. Derin Wester, and Dr. Michael Hoffer, in the offices at San Diego, Wilmette, and Merrillville as co-investigator in testing and treating patients with the VR system to investigate the modulation of the VOR gain values in decreasing dizziness and imbalance problems.