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# Portable Virtual Vestibular Stimulation

Synnott, J., McCullagh, P. J., Kelly, G. P., McAllister, H. G., and Houston, H. G.

**Abstract**— Vestibular dysfunction is associated with the developmental delay of motor and attention skills. Integrity of the vestibular and visual systems manifest in rapid side to side eye movement called nystagmus. This may be evoked by physical rotation or caloric stimulation to the ear drums. The approach in this technological advance explores whether controlled rotation of the environment can induce the nystagmus in healthy adult subjects. This provides a portable solution which utilizes technology associated with virtual reality. VR allows a level of control not possible in the 'real' world and allows the therapist a degree of control over the environment that is not normally possible. Initial testing illustrates that nystagmus is apparent in the electro-ocular recording during stimulation, but so far, does not persist beyond the stimulation period.

**Index Terms**— *Nystagmus, Virtual Reality, Optokinetic, Vection, Vestibular System*

## I. INTRODUCTION

SENSORY integration theory [1] suggests that a lack of integration between the visual and vestibular systems in young children can lead to delayed development of motor skills, postural reflexes, coordinated eye movements and visual attention skills. Vestibular dysfunction is found in a number of disorders, including, but not limited to, autism, developmental delay, cerebral palsy, traumatic brain injury, attention deficit disorder, stroke, blindness, and hearing impairment [2]. The most prominent objective sign of vestibular involvement is nystagmus (spasmodic, rapid movement of the eyeball from side to side). This reflex movement results from stimulation of the semicircular canals of the vestibular system, visual stimulation, or, in some cases, brain disorder [3].

Traditional methods for identifying vestibular dysfunction in young children are either unreliable or require expensive, bulky, clinical equipment. For example, the observation of the duration of nystagmus following rotation has been used to evaluate vestibular function. The Southern California

Postrotary Nystagmus Test [3] determines the degree of normalcy – or otherwise – of a child's postrotary nystagmus and from the results inferences can be drawn about some of the brain's integrative responses. To test for the duration of nystagmus, the subject is passively rotated anticlockwise on a board 10 times in 20 seconds and then abruptly stopped. The period during which the subject's eyes move back and forth involuntarily following stopping is timed to the nearest second and the maximal excursion of the eyeball is noted. The procedure is repeated, in a clockwise rotation.

However, many factors contribute to post-rotary nystagmus (PRN) and it is not clear whether or not the PRN change is due to change in central nervous system physiology or to other factors.

Research [2] has shown many benefits from vestibular stimulation therapy including decreased self stimulation, decreased hypersensitivity, increased postural security, increased concentration and attentiveness, increased balance, increased body awareness, calming effects, reduction of abnormal muscle tone at slow speeds and increased alertness at high speeds. Stimulation of the vestibular system is believed to improve gross motor co-ordination, reflex integration, equilibrium, intellectual functioning, perceptual-motor skills, auditory language skills and socio-emotional development in children [1].

Kelly [4] reviewed the use of rotary vestibular stimulation to treat a wide variety of neurological disorders. The majority of studies, however, are rife with methodological problems. For example, many of them employed clinically unreliable assessments of vestibular function. Test-retest reliability for many of them has not been stated and so this introduces problems of subjectivity and experimenter bias leading to possible errors of measurement. Electrical recording of eye movements is generally considered an essential adjunct to clinical vestibular testing but many of these studies rely on visual observation of vestibular responses.

Conventional methods of vestibular stimulation (such as physically spinning or accelerating the patient) can be ineffective as too many other sensory systems are affected at the same time.

Virtual Reality (VR) appears to have the potential to address some of the limitations of conventional vestibular therapy. It may be possible, for example, to develop objective criteria that the therapist can use to evaluate the client in a safe manner. It can be instituted systematically and carefully to safely control interactions with the virtual environment without real world hazards. VR allows a level of control not possible in the 'real' world and allows the

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J. Synnott is with the School of Computing and Mathematics, University of Ulster (e-mail: synnott-j@email.ulster.ac.uk).

P.J. McCullagh is with the School of Computing and Mathematics, University of Ulster (e-mail: pj.mccullagh@ulster.ac.uk).

G.P. Kelly is with the School of Health Sciences, University of Ulster (e-mail: gp.kelly@ulster.ac.uk).

H.G. McAllister is with the School of Computing and Mathematics, University of Ulster (e-mail: hg.mcallister@ulster.ac.uk).

H.G. Houston is a Principle Audiological Scientist with the Belfast Trust (e-mail: glen.houston@belfasttrust.hscni.net)

therapist a degree of control over the environment that is not normally possible. It is also the only method whereby a client can be exposed to life like scenes of increasing complexity while being closely monitored for safety.

Viirre and Buskirk [5] have described the use of virtual reality (VR) to enhance vestibular rehabilitation in an adult population, suggesting that it may provide a more effective method of both assessing vestibular function and providing controlled vestibular stimulation. Jacobson et al [6] have expanded upon this idea through the development of the Balance Near Automatic Virtual Environment (BNAVE), an immersive stereoscopic virtual reality display. The use of VR may, indeed, facilitate the use of objective evaluation of nystagmus data, which is normally assessed by an experienced clinician.

The visual system interacts strongly with the vestibular system, as both sensory modalities are directly related to spatial processing. When visual and vestibular signals conflict, it is possible that the dominance of vision in perceiving spatial orientation may cause recalibration of the vestibular system. Providing visual input from a virtual environment that replicates the sensation of spinning rapidly may, therefore, reproduce the sensation of spinning in the vestibular system. This false perception of self-motion in a virtual environment is known as “vection”, and has been the focus of many studies.

Riecke et al [7] highlight advantages of scene consistency and spatial presence in achieving vection, over the use of abstract imagery such as the black and white lines commonly used in optokinetic drums. By using a natural and consistent scene, vection can be achieved more quickly and with greater effect. Mohler and Riecke [8] describe how rotation provides a more convincing experience than linear motion, and how the sense of vection in both scenarios can be improved by allowing the user to see the floor and ceiling as a reference point. The effects of foreground stimulus and static point fixation have been found to have an impact on the intensity and onset time. Nakamura and Sinji [9] found that a foreground which was either static or slowly moving in the opposite direction of the background facilitated vection.

Becker et al [10] carried out a detailed study into the effect of voluntary suppression of the optokinetic reflex when exposed to optokinetic stimulus. This study involved exposure to the stimulus under different viewing conditions, and it was found that fixation on a single stationary point provided the most rapid onset and highest intensity of vection. Interestingly, the study found that the worst results were obtained when participants observed the stimulus with the most natural reaction; to repeatedly focus on and track various areas of the stimulus, therefore not suppressing the optokinetic reflex.

Riecke et al [11] state that the use of either a stationary focal point or foreground stimuli in front of a moving background stimulus facilitates the more rapid and intense

onset of vection by creating greater “relative motion” on the retina.

## II. METHODOLOGY

A browser based solution written in JavaScript and HTML has been developed. The solution uses QuickTime VR (QTVR), a file format which caters for creation of 360 degree interactive panoramic images. These QTVR files, created from panoramic photographs, provide the appearance of an enveloping environment by distorting the image displayed in the peripheral areas of the viewport, providing the illusion of viewpoint rotation rather than horizontal image scrolling, i.e. circular vection rather than translational vection. This provides an optokinetic stimulus. The DevalVR (<http://www.devalvr.com/>) browser plug-in was used in order to gain access to a number of parameters, allowing the user to interact with the QTVR files within a browser using HTML form buttons, check boxes, and text boxes.

The QTVR files were created using digital photographs taken around the University of Ulster's Jordanstown campus. These photographs were then stitched together using AutoStitch (<http://www.autostitch.net>), which analyses each photograph in a panoramic series and merges them together seamlessly, creating one large panoramic image.

The panoramic image was then imported into PanoCube (<http://www.panoshow.com/panocube.htm>), which converts the image into the QuickTime VR format. Fig. 1 shows the architecture of the developed software.

An interface provides the researcher with a number of controls: image to be displayed, the rotational velocity in degrees per second, and the direction of the rotation. A session timer has also been included, allowing the setting of a specific duration of the optokinetic stimulus. Once the timer expires, a focal point is displayed which the subject is instructed to look at, causing vection and potentially inducing nystagmus.

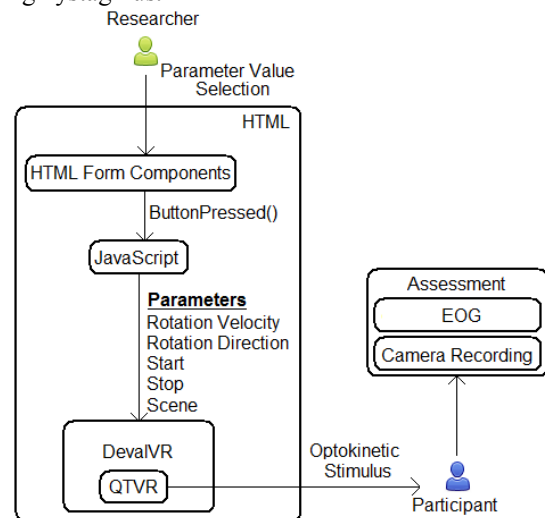


Fig. 1. The architecture of the developed software

A trial involved two subjects who were exposed to the stimulus under three different conditions, and an audiologist who was responsible for placement of EOG electrodes and analysis of the output signal. In order to satisfy ethical criteria, both subjects were asked to complete a consent form which asked for some brief medical history in relation to past experience with motion sickness. Both participants were believed to be healthy, with no known vestibular dysfunction.

Before exposure to the stimulus, each participant underwent an electrooculogram (EOG) calibration phase which involved fixating on an illuminated visual target displayed at varying positions a horizontal display. Once calibration was complete, the participants were exposed to optokinetic stimulus in three forms: Curved optokinetic display screen, laptop screen, and virtual reality (VR) goggles. The curved optokinetic display screen is used in clinical practice as a source of optokinetic stimulus by displaying a grid of red light emitting diodes on a black background moving at a constant rotational velocity, and served as a comparison to the stimulus developed for this project. The laptop screen used was a backlit 13.3" widescreen LED display belonging to a Dell XPS M1330 ultraportable laptop which was placed at eye level approximately 50 inches from the subject's eyes. The VR goggles used were a pair of Vuzix iWear VR920 goggles which claim to produce a display "equivalent to a 62 inch screen". The stimulus developed for this project was displayed on both the laptop and VR goggles.

All trials were carried out in a darkened room in order to minimize distractions and to ensure focus was maintained on the stimulus. Subjects were exposed to the stimulus for 60 seconds, and then asked to count backwards whilst either closing their eyes or fixating on a focal point at the centre of the display. EOG monitoring was continued for 30 seconds after exposure to the stimulus had ended, and was carried out in two ways: EOG (as mentioned), and visual recording by webcam. Fig. 2 shows the setup used.

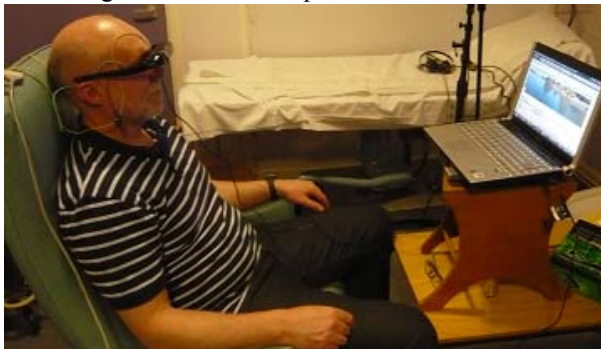


Fig. 2. Trial setup comprising visual stimulation and EOG recording

### III. RESULTS

The software simplifies nystagmus induction and detection by providing full control over all of the characteristics of the optokinetic stimulus that would be of importance to a clinician. Additionally, the software automates many of the typical tasks required throughout.

The results of the test were obtained by analyzing the EOG signal generated during and immediately after exposure to each of the different forms of optokinetic stimulus. Analysis of the EOG wave during exposure to the optokinetic stimulus in all three forms (optokinetic screen, laptop screen, VR goggles) provided a strong characteristic "saw tooth" waveform indicating nystagmus [12]. Interestingly, one subject experienced a larger sense of vection and displayed a more prominent nystagmus waveform than the other, especially when using the VR goggles.

Also found during exposure to the stimulus was that optokinetic nystagmus did not occur constantly throughout exposure. It was found that there were occasional brief seconds of eye inactivity throughout, despite a lack of



Fig. 3. EOG results during and after exposure to stimulus

distractions in the environment.

After 60 seconds of exposure to the stimulus, the subject was asked to either close their eyes while counting backwards, or to keep their eyes open and stare at a focal point which was placed on screen on a plain white background. Both situations presented similar results; no noticeable after nystagmus was detected either through EOG analysis or visual analysis. Fig. 3 shows the EOG waveform during and after exposure to the stimulus. This figure shows three iterations of eye movements which are indicative of optokinetic nystagmus. It can then be seen that the eye movements stop as exposure ends.

### IV. DISCUSSION

A software based solution to virtual vestibular stimulation has been developed, which provides the option for portable testing, appropriate to clinical neurological departments. The software generates a realistic rotating scene, providing an optokinetic stimulus which can be adjusted to suit a researcher's needs by adjusting parameters through the use of a browser based user interface.

The results from the initial recording do not provide evidence of after-nystagmus once exposure to optokinetic stimulus has ended. This may indicate that a rotating stimulus alone which induces circular vection is not enough to cause recalibration of the vestibular system. This is

possibly due to the number of other sensory queues present that suggest to the subject that physical movement is not occurring. Riecke et al [13] carried out an investigation into the effects on obtaining vection by providing a situation where movement seems possible, by removing or distorting sensory input. This was done by exposing subjects to a rotating auditory stimulus, whilst seating them on a hammock with their feet suspended above the ground. Finally, vibrations were passed through the hammock, adding further sensory distortion. This was found to increase the sense of vection experienced by subjects. More recent studies [14] further state the benefit that realistic rotational audio stimuli can have on obtaining a sense of presence and vection.

It is possible that exposure to a visual stimulus alone does not provide a sufficiently convincing experience, and that by removing or distorting many of the additional sensory queues that indicate to the subject that they are stationary, such as the auditory, visual, and touch senses, the vestibular system may be overridden, resulting in a stronger sense of vection and ultimately leading to after-nystagmus after exposure to the stimuli. If these conditions are able to induce after-nystagmus, there is the unfortunate disadvantage of the setup being much more complicated, expensive, and less portable than would be desired from a virtual solution.

Further study must be made into specifying the ideal display format for optokinetic stimulus. When carrying out the trial, it was found that one subject experienced a higher sense of vection than the other. This may have been due to the idea of circular vection being facilitated by believability of the optokinetic stimulus as a “stable scene” [7]. Indeed, this same subject expressed preference to the VR goggles for providing a better viewing experience, whereas the other subject found the VR goggles to be unconvincing, and found it obvious that they were looking at two small screens rather than the large 62 inch screen which the VR goggles aim to simulate. This subject experienced little to no vection, and produced significantly smaller optokinetic nystagmus waveforms. There is room for investigation into why some subjects are more susceptible to believing a virtual reality scene is “real”, and are in turn more susceptible to vection.

Another observation made during the test was that optokinetic nystagmus during exposure to the optokinetic stimulus was not constant. Periods of eye inactivity were experienced, despite efforts by the subjects to maintain concentration, and it is a possibility that these periods of disconnection from the stimulus could have a significant effect on the overall effectiveness. The periods of inactivity are most likely due to either loss of concentration or habituation due to prolonged exposure. It would be worthwhile to investigate the possibility of adding variation to the stimulus in order to maintain concentration and prevent habituation. This variation in the stimulus could be implemented by changing the color of an object in the stimulus each time a certain number of rotations are complete, and asking the subject to remember each of the

colors used. Once exposure to the stimulus is complete, the subject could repeat the colors seen in the stimulus, serving as a distraction from the post-exposure EOG analysis and insuring the subject maintained concentration throughout exposure.

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