Experimental Analysis of Virtual Reality as a Stimulus in Posturography

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As a Stimulus in Posturography

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Experimental Analysis of Virtual Reality as a Stimulus in Posturography. (Esperimentall analys av virtuell verklighet som stimulus i posturografi)

Abstract
The aim of this Master Thesis was to measure and quantify the effect of a continuous visual stimulus on postural stability. The visual stimulus was applied using a Head Mounted Display through which the image of a vertically rotating cylinder was projected. It was hoped that the relationship between the speed of rotation of the cylinder and the body sway of the subject would be quantified through the process of System Identification. By creating a model of how a healthy subject reacts to the visual stimulus it is hoped that this technology may be used to diagnose and treat those with deficient postural control.

Keywords

Classification system and/or index terms (if any)

Supplementary bibliographical information

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Part I: Introduction, Hypotheses and Design

1.0 Introduction

In order to ensure that this Master Thesis is self contained and thorough in nature, it is essential to outline the background and highlight the fundamental aspects of this work. The analysis carried out is intended as an extension of [1] and it is hoped that the effect of a changing visual stimulus on human postural dynamics will be added to vestibular and proprioceptive stimuli already tested.

It is clear that there are three main aspects to the work being carried out, these are as follows:

- Postural Stability
- Virtual Reality
- System Identification

1.1 Postural Stability

As may be seen from Figure 1 the process of maintaining upright stance may be represented as a feedback control process
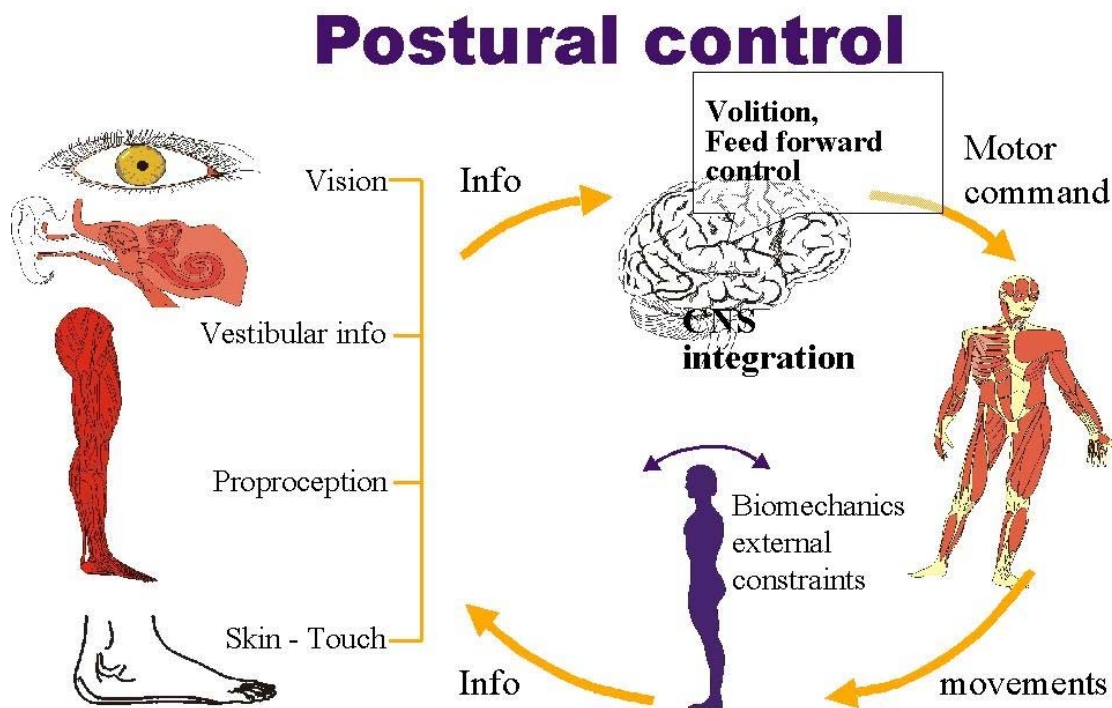
Figure 1 - Human Postural Control System

Using information received from the opto-kinetic, vestibular and proprioceptive inputs and using the brain as a control which assesses the inputs and relays a corresponding response which manifests itself through subsequent skeletal motion. The body is restricted to an angle to which it may be tilted before the brain is unable to provide a response that does not involve taking "evasive" action.

Previous tests carried out in Dept of ENT, Lund University, Sweden have focussed primarily on the response of this system when disturbances were applied to the vestibular and proprioceptive inputs. Experimentation using the visual stimulus was limited to subjects standing either with eyes open and fixed on a particular object or with eyes closed although it should be noted that previous attempts at using visual stimulus have been used, this is the first time that virtual reality has been considered.

In the following sections the Vestibular system (1.1.1) and the Velocity Storage System (1.1.2) will be drawn out in order to give a clearer understanding of the mechanisms being stimulated such that they may be subsequently manipulated to bring about the maximum response.

1.1.1 The Vestibular System

In order to maintain upright posture, the human being reacts on information received from proprioceptive, vestibular and visual feedback paths the result of which is manifested in the vestibular and locomotor systems. Injuries to these feedback paths or to the central nervous system may result in impaired postural control.

The human vestibular system, as may be seen in Figure 2, has evolved to detect acceleration and velocity stimuli, which it is also able to do without additional visual and somesthetic information. The vestibular organ is sensitive to both linear and angular acceleration which are caused both by self motion and gravity. These accelerations are detected by the otolith organs and semi-circular canals respectively. It is essential to detail how these components work such that an appreciation of how they may be manipulated for the purpose of posturography may be gained.

Otolith Organs: The Otolith organs of the inner ear, detect the linear accelerations using the utricles and the saccules furthermore; they detect angular motion that causes alterations in the earth's gravity vector relative to the subject's body. The otolith organs also detect changes in the magnitude or direction of linear gravitointertial force vectors using hair cell mechanreceptors. The mechanoreceptors are embedded in gelatinous membranes containing crystals of calcium carbonate; these crystals are known as otoconia. Given that the otoconia are denser than their surroundings they tend to lag behind any motions of the head. With motions of the head, the otoconia move and cause subsequent deformation of the hair cells.

Semicircular Canals: These are also located in the inner ear and are responsible for the detection of angular motion. They are arranged in three, approximately orthogonal axes. Each canal is filled with a gelatinous liquid known as cupula. The cupula is also embedded with hair cells that undergo deformation when the cupula is deformed by changes in fluid pressure caused by angular acceleration of the semi circular canals.

The Otolith organs and the Semicircular canals comprise the equilibrium organs of the non-auditory parts of the human labyrinth; they interact with each other, as well as with other sensory organs, during moments involving complex linear and angular accelerations. The Vestibular system itself is involved in many aspects of human life; as well as perception of acceleration; it is responsible for the reflexive control of gaze stabilisation, head orientation, coordinated locomotion, certain reach reflexes and postural equilibrium.

It is hoped that the properties of perceptions of acceleration may be exploited to bring about change in postural equilibrium.
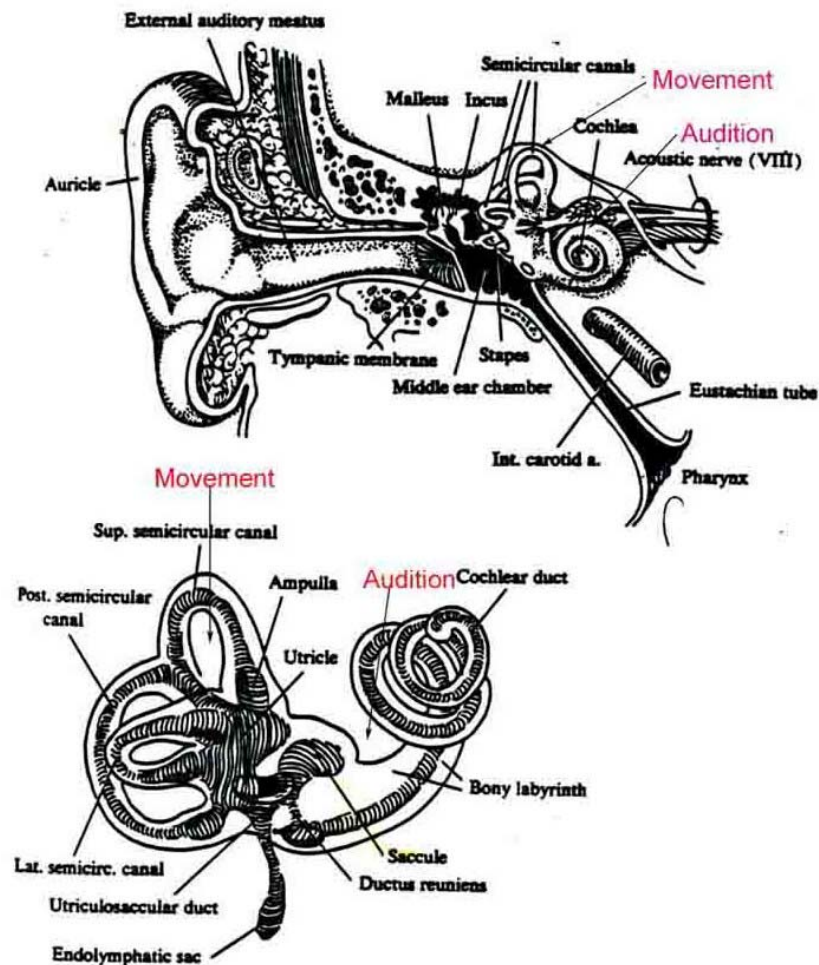
Figure 2 - Vestibular System

1.1.2 The Velocity Storage Mechanism

The ability of the human body to maintain upright stance is clearly not determined solely by the vestibular system. When dealing with the effects of changing visual stimulus it is essential to discuss the interaction of the vision mechanism and the vestibular system and the actions undertaken when tracking a point travelling at a given velocity.

Maintaining a clear vision whilst the head is moving is a result of the interaction between many sensory neural systems of which the vestibular and visual systems are the most important. The interaction of these two systems allows maintenance of a stable retinal pattern and thus sufficient visual awareness. Research in recent times has revealed that this relationship is controlled at a subcortical level, assumed to be in the brainstem, where the visual and vestibular inputs are modulated by a common, non-linear function, known as the "Velocity Storage Mechanism[1]."

As mentioned in the previous section, the semi-circular canals act as accelerometers which convert accelerations of the head into a signal which represents the velocity of the head; this is part of the Vestibulo-Ocular Reflex (VOR). Their mechanical orientation allows rapid response. When the head moves, the VOR maintains retinal image stability by creating conjugate eye movements that are opposite to those of the head. A simple test is to have a subject instructed to fix his/her gaze on a particular target, and thus moving the head to the left and right while trying to keep the target in focus.

For the purposes of this master thesis, it is essential to discuss the velocity storage mechanism when applied to the optokinetic reflex. Prolonged movements, for at least a 6 seconds, of the entire visual surround, as might occur when driving a car or when using virtual reality, cause corresponding eye movements; Optokinetic Nystagmus (OKN); which is triggered by image slip of the retina. In human subjects, OKN is produced by interactions between the cortical and subcortical optokinetic mechanisms. It is essential, given the characteristics of the Velocity Storage Mechanism, that any visual field designed to elicit postural response maintains a particular velocity for at least 6 seconds such that the storage mechanism is able to make appropriate adjustments to any change in state of the environment.

In engineering terms one may think of the Vestibulo-Ocular Reflex as similar to the Kalman Filter[2] which tries to minimise the output error variance, the Retinal Slip between the actual position of an object in the visual path and the model of where the subject perceives that object to be.

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[1] A full discussion of the Velocity Storage Mechanism may be found in [13]
[2] More information on the Kalman Filter and other aspects of Computer Controlled Systems may be found in [19]

1.3 Virtual Reality

By definition, a virtual environment[3] is a synthetic computer generated environment designed to give a user an experience of being in a particular place or carrying out a particular action without having to be in the real environment. This technology has applications in medical treatment, military training and entertainment to name but a few. One of the purposes of this Master Thesis is to create a virtual environment which causes controlled disturbances in a subject's postural stability.

In order to elicit a significant disturbance from the postural equilibrium using a virtual reality stimulus it is essential that the subject perceives some kind of angular or linear acceleration. The methods to bring this about may be roughly split into two categories:

> i. Methods involving the acceleration of the user
> ii. Methods not involving the acceleration of the user

Given the nature of the posturographic tests, with the subject standing in a fixed-feet position while the stimuli are applied, methods involving direct acceleration of the user are rendered useless and will not be discussed further. Methods not involving the acceleration of the user may be subdivided as follows:

> a. Visual Field Motion
> b. Auditory Surround Motion
> c. Tactile Surround Motion
> d. Voluntary Tactile/Kinesthetic Behaviours
> e. Vibration of Localised Body regions
> f. Acoustic vibrations
> g. Caloric Stimulation of Ear Canal
> h. Direct Electrical Stimulation of Vestibular Nerve Fibres
> i. Drug Treatments

a, e, i and h have been the subject of previous posturographic tests conducted in ENT, Lund University Hospital. The focus of this Master Thesis is the use of a., although it should be noted that a combination of these may be used to further enhance the sensation.

The virtual environment is displayed, during this work, using the i-visor DH-4400VP Head Mounted Display[4] (See Figure 3 on next page) .

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[3] For further information on Virtual Environments consult [24]
[4] See Appendix for technical specifications of DH-4400VP

Figure 3 - DH-4400VP Head Mounted Display

It should be noted that the field of vision is limited to 31˚ across the diagonal and hence the effect would almost certainly be less than that of a HMD with a larger field of view. As the design process will show, there are ways of maximising the effect of virtual reality such that the limited field of vision of the glasses is not a substantial obstacle.

The human ability to differentiate reality from illusion is such that considerable time must be put into designing a virtual environment that will not only elicit a disturbing effect on the postural stability of subjects under test but provide suitable data for system identification. As will be show in section 3, a number of ideas were considered and tried before the final environment was decided upon.

1.2 System Identification

System Identification[5] is the process of deriving the description of a system based on the output response of a given system when perturbed with a given input or inputs. The description is thus called the model of the system.

One of the proposed purposes of this Master Thesis is thus to create a model of the standing human being when excited by a changing visual stimulus. The question may be raised of why such models are required. The answer is that using the model, an idea may be formulated of how a healthy human being could and should react to a given visual stimulus; from this an improved scientific analysis may be applied to those who have degenerated postural control.

The model used in [1] to describe the stance of a human subject is that of an inverted pendulum (See Figure 4) used with a feedback control strategy. For small perturbations from the unstable, upright equilibrium a linear model may be used to describe such dynamics; furthermore, spectral analysis and Laplace transform methods may be used for interpretation of input/output data.
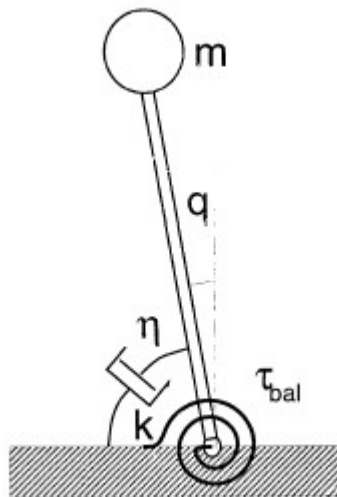
Figure 4 - Inverted Pendulum Model (See [14] for further information)

When the body is exposed to perturbations in the anterior-posterior plane it may employ at least two methods to maintain upright equilibrium, the so-called ankle strategy and hip strategy. In ankle strategy, muscular forces operate around the ankle; during hip strategy, the muscles flex around the knees and hips depending largely on shear forces. For small perturbations, the ankle strategy is sufficient to maintain equilibrium, for major perturbations hip strategy must be employed. In the most extreme cases, the subject is unable to counteract the disturbance and thus falls over.

The minor perturbations used and the subsequent correction of the human body in the studies carried out allow use of the inverted pendulum model. It should be noted that the model is valid only for perturbations in the anterior-posterior plane and that the

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[5] More information on System Identification may be found in [2]

inverted pendulum may be seen as having an unstable equilibrium point at $\theta = 0$ and thus stabilising forces must react to disturbing forces to maintain this unstable equilibrium. As a result of these observations, the model is extended to an inverted pendulum to describe the motion of the body and a control system for balance which may be thought of as a shock absorber in an automobile. The uprightness of the subject may be modelled as a spring constant, k, and a damping force, η; these maintain the unstable equilibrium and are able to react against disturbance. Thus, the "quality" of response to a disturbance is determined by the values of k, η in addition to the mass of the subject, m (kg), and the distance of the subject's centre of mass from the platform, l (m).

There are further assumptions that must be made to ensure that the model is formalised and remains valid and that a transfer function for the system may be identified, these are described as follows:

     1. The body is rigid and has mass, m (kg)
     2. The body centre of mass is located at a distance l (m) from the platform
     3. For a standing human being, there exists a dynamic equilibrium between the torque exerted by the foot and the forces acting on the "inverted pendulum."

Introducing J, as the body moment of inertia around the ankle joint and the tangential torque equilibrium for a subject to a gravitational acceleration g, is thus:

$$J\frac{d^2\theta}{dt^2} = mgl\sin\theta(t); \; J = ml^2$$

It may be seen that there is no stable equilibrium at $\theta = 0$ (See [15] for more information on Non-linear dynamics); furthermore a subject who does not counteract the force of gravity will invariably fall.

The following assumptions must be made to model a "balance" action and the effects of disturbances:

     4. There is a stabilising ankle torque, $T_{bal}(t)$
     5. There is a disturbance torque, $T_d(t)$, from the environment

The torque balance equation then becomes:

$$J\frac{d^2\theta}{dt^2} = mgl\sin\theta(t) + T_{bal}(t) + T_d(t); \; J = ml^2$$

     6. $T_{bal}(t)$ is produced by a PID controller, with the P,I and D components determined by the k, η and ρ.

$$P : -mgl\sin\theta(t) - kJ\theta(t)$$

$$D : -\eta J\,\dot{\theta}(t)$$

$$I : -\rho J\int_{t_0}^{t}\theta(t)dt$$

According to the Routh Hurwitz stability criterion (see [16] for further details), the P and D components are vital for stability, specifically, it is required that k, η > 0 for stability. I represents slow compensation of bias in θ and is not vital for stability.

The last assumption made deals with the model of the vibration stimulus:

> 7. A vibration, v, acts as a disturbing input into the stabilizing system; this

causes an error in the position θ (stretch) and the angular velocity $\dot{\theta}$ (rate), hence the P and D components become:

$$P : -mgl\sin\theta(t) - kJ\theta(t) + b_1 v(t)$$

$$D : -\eta J\,\dot{\theta}(t) + b_2 v(t)$$

b_1 and b_2 are chosen to represent the fact that both the stretch and rate perception are affected, albeit with different proportions.

The transfer function can therefore be calculated as follows:

$$J\frac{d^2\theta}{dt^2} = mgl\sin\theta(t) + T_{bal}(t) + T_d(t)$$

$$T_{bal}(t) = -mgl\sin\theta(t) - kJ\theta(t) - \eta J\,\dot{\theta}(t) - \rho J\int_{t_o}^{t}\theta(t)dt$$

Using the two expressions above it and the fact that there are three states which affect the equilibrium: angular velocity dθ/dt, angular position θ, and bias compensation, an expression for the required torque balance according to a given disturbance and vibration stimulus is given as follows:

$$T_{bal}(s) = \frac{(b_1 + b_2)(s^3 - \frac{g}{l}s^2)}{s^3 + \eta s^2 + ks + \rho}V(s) - \frac{\eta s^2 + (k + \frac{g}{l})s + \rho}{s^3 + \eta s^2 + ks + \rho}T_d(s)$$

Given this transfer function, k and η must be estimated, and it may also be determined if there is any additional integral action.

Forces on the platform:

From the Appendix it may be seen that μ is related to T_{bal} for a given mass resulting in the following relationship:

$$\mu(t) = \frac{2\gamma}{a+b}T_{bal}(t) + \gamma\frac{b-a}{a+b}mg$$

For positions a and b; with γ as a gain factor. Hence, μ is the representation of T_{bal} adjusted by a gain and bias term which are thus adjusted for when the measurements are recorded.

2.0 Experimental Hypotheses

It is hoped that the use of virtual reality as an external stimulus in posturography will prove the following hypotheses:

1. Virtual reality has an effect instabilizing effect on postural stability when used with other stimuli e.g. vibratory stimulation of the Gastronemius muscles

2. The use of virtual reality, specifically the Cy-Visor HMD along with the "Vertical Rotating Cylinder" pattern will cause some subjects to become nauseous.

3. The sight of the rotating cylinder will induce a resulting swaying motion in the subject.

4. The direction of sway will show correlation between the directions of rotation of the cylinder more specifically:
    i. If the cylinder is rotating forward (/backward), the subject will have a tendency to lean forward (/backward)
    ii. If the cylinder is rolled leftwards (/rightwards), the subject will have a tendency to lean leftwards (/rightwards)

5. The Rotating Cylinder will only be effective up to a maximum, as yet undetermined, rotation speed

It should be noted that this is one of the first studies of its kind and as such the hypotheses may all turn out to be false however, the results will no doubt help to shape future hypotheses made when similar experiments are carried out. Furthermore the time scale set out for this Master Thesis may be insufficient to test all of these hypotheses.

Previous tests dealing with the effect of Virtual Reality on postural stability have dealt mainly with the resulting effects on postural control after immersion in a given environment by comparing quiescent stance before and after immersion. As mentioned already, the tests conducted as part of this master thesis will deal with "real-time" posturography i.e. attempting to correlate the sway of a subject to the visual stimulus being used on the HMD.

3.0 Design of Virtual Reality Environment

In the following sections a description of the process of designing and testing a Virtual Environment suitable for use in posturographic tests will be described. The full course of design will be described, including the previous types of visual stimulus used (3.1), the theory behind eliciting the maximum visual effect (3.2), ideas for new environments (3.3), creating a full immersive environment (3.4), the final design (3.5) as well as any further issues concerning further development of the design.

It should be noted that the final design was produced using the World Up virtual environment development software. World Up is a script based language allowing changes of environment variables and subsequent rendering of frames to occur in real time.

3.1 Previous types of visual stimulus used

As mentioned earlier, the posturographic tests carried out involve subjects stood either with eyes open or eyes closed however, attempts at devising and using a changing visual stimulus have been made before. As part of the process of building a successful virtual environment it is important to know what has been tried in the past and what has been unsuccessful in inducing the correct effect. As with any scientific process, each unsuccessful attempt gives ideas to what may be tried next.

Previous attempts at using visual stimulus have involved subjects looking at actual moving stimulus. The two that warrant the most attention are the moving screen and the optokinetic drum. Figure 5 depicts a white screen with vertical black stripes of non-uniform width and non-uniform separation. Subjects were asked to stand on the force platform, with the screen positioned in front of it, and look at the screen as it moved.

Figure 5 - Optokinetic Screen

This method of eliciting postural sway through visual stimulus turned out to be a considerable failure with no notable results quantitative results being ascertained.

As described in [11], an optokinetic drum was used to induce optokinetic after-nystagmus. The drum was 1.8 metres in diameter with 10cm wide black and white vertical stripes covering the entire visual field. The subject was instructed to look directly ahead; the drum was set to rotate at 90˚/s for 60 seconds before the extent of nystagmus was measured. (See Figure 6 below)

Figure 6 - Optokinetic Drum

Current tests, similar to those described in section 4, involve patients standing either with their eyes open and fixed on a point 1.5 metres away on the wall or with their eyes closed. The intention behind these two orientations is to test the ability of the subject to maintain upright posture in the presence of other stimuli, either vestibular or galvanic, when they do and do not have an awareness of their spatial position. Thus a static optokinetic stimulus and a zero-optokinetic stimulus are being tested; the next stage is to test postural stability using a dynamic stimulus.

3.2 Eliciting the maximum effect from visual stimulus

The sensation of motion from a virtual or real environment is known as vection. An everyday occurrence of vection can be seen when sat in a stationary train in a train station; a neighbouring train begins to move but those sat in the stationary train, feel as though they are moving and make the appropriate bodily adjustments. This illusion ceases when the travellers in the stationary train realise their train is not moving. In order to create an effective visual stimulus that is useful for posturographic experiments it is essential that subjects under test gain the appropriate sense of vection. As explained in section 1, attention must also be given to the Velocity storage mechanism, which requires approximately 6 seconds to adjust to viewing objects travelling at a given speed. It is therefore suggested that there should be at least a 6 second delay in between changes in speeds in the final virtual environment.

From the experimentation carried out in section 4 it was seen that many of the subjects under test suggested that the virtual reality could be improved by making the virtual environment more immersive. Patients complained, during experiments using the HMD, that on moving their head either left or right they were still able to see the whole of the cylinder (see Figure 9 and Section 4). In a real situation, when the eyes track in the same direction as the movement of the head which means the eyes focus on a different part of the visual field.

It was required to add functionality that would allow the subject to make small head movements and the environment to react accordingly. For this function the "Flock of Birds" magnetic tracking device[6] was incorporated into the software. The "Flock of Birds" device was locked to the viewing point of the simulation (the centre of the sphere), from this point a six degree of freedom view was allowed. Essentially, the view of the subject was locked to the centre of the cylinder and from the point the subject is able to look up, down, left and right while the cylinder rotates (See Figure 7 and Figure 8). The draw back to this is that no forward or backward motion is allowed; it was felt that to allow this would cause unnecessary difficulty in setting the initial position of the device during final testing. The tracking device was mounted on a sports hat using Velcro and tape to attach it. Furthermore, it was seen as necessary to reduce the movement sensitivity of the "Flock of Birds" to ensure that the view seen was not jittery.

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[6] See Appendix for Technical Specifications of the Flock of Birds Device
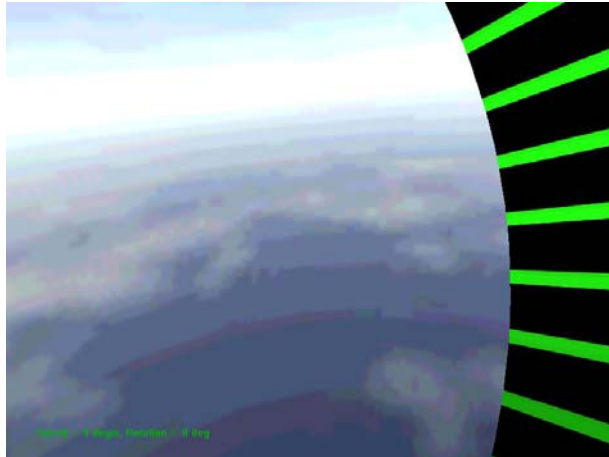
Figure 7 - Image as the user looks leftwards
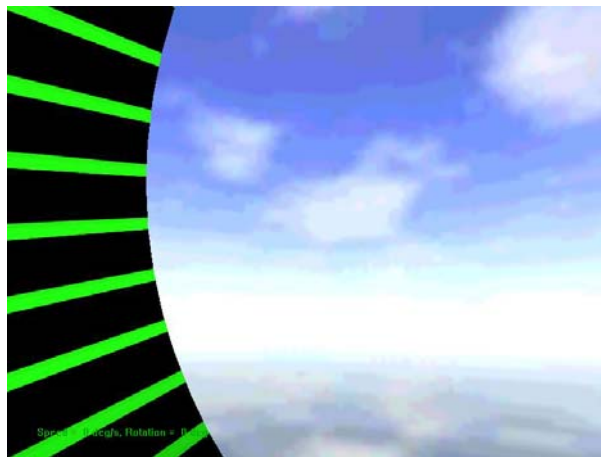
Figure 8 - Image as the user looks rightwards

As mentioned in the introduction, the use of an additional auditory stimulus may be used to enhance the effect of the visual stimulus and thus make the virtual environment more immersive. In previous posturographic tests experiments were generally carried out with the patients having their open or closed. The auditory stimulus came in the form of a piece of classical music, in [11] this was Haffner Serenade, 2nd and 3rd movements, W.A. Mozart, KV 250. The use of music was designed to distract the subject from ambient noise which may give a heightened sense of spatial perception and thus reduce the disturbance from the equilibrium position.

It was felt that for the final series of tests that experimentation should be carried out with a sound which in someway enhanced the environment either by cutting off the auditory channel by being sufficiently distorting in nature or by enhancing the visual pattern. It was thus decided that the cylinder would be set to rotate against the sound of a waterfall. This sound was both distorting and also gave the subject a cognitive reference. It is hoped that the virtual environment will eventually incorporate the Doppler sound effect such that the volume, pitch and tone of any sounds played will change according the rotation speed and angle of the cylinder.

3.3 Design ideas and developments

The following section contains all of the ideas that were considered and tried before the final design was decided upon. Each of the merits and negatives of these will be briefly described before the inspiration and implementation of the final design is discussed. The ideas proposed may be roughly split into two categories:

1. Environments with no cognitive reference points
2. Environments with cognitive reference points

This alludes to the fact that in certain environments, as in [20] and [21], an environment was used that involved the motion of generally black and white patterns in a particular fashion. It is almost certain that subjects used in such experimentation would have no previous experience of seeing such visual pattern. Environments with cognitive reference points allude to the use of video games or pre-recorded video images as in [22] and [23]. In such tests subjects certainly could have had exposure to such imagery before the tests took place. It is hoped that, as will be shown in the final design, that by blending cognitive and non-cognitive reference points an environment, effective in the analysis of postural control, will be created.

3.3.1 Virtual Rotating Cylinder

Initial tests with virtual reality involved computer generated simulations of the real stimulus used. A black and white cylinder (See Figure 9 below) was created in World Up similar to that used in [11]. The rotation speed of the cylinder could be adjusted with appropriate key strokes furthermore. The cylinder was set to rotated around its centre point, however, the whole cylinder could also be set to rotate giving any viewer the impression that they themselves were moving inside the rotating cylinder. This environment proved successful in the tests described in Section 4, which were designed to give an initial impression of whether or not virtual reality would be effective in eliciting postural sway, however, it was felt that it lacked anything that subjects would have cognition of.
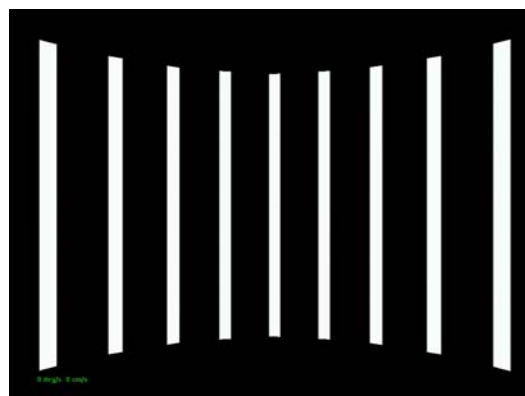
Figure 9 - Virtual Cylinder to induce lateral sway

3.3.2 Rotating Cylinders
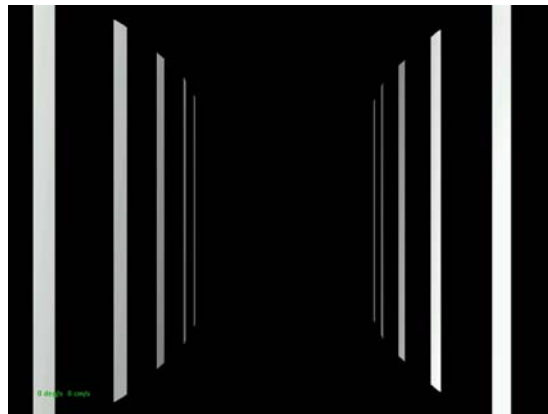
Figure 10 - Virtual Passage creating by two rotating cylinders

Figure 10 shows two black and white striped cylinders capable of being moved either both in the same direction and at the same speed, thus giving the subject the impression of being moved straight forward or backward, or in opposite directions at and different relative speeds thus giving the subject the impression of moving in a curved path. Given that this work is the first of its kind it should be stated that if tests with the final design outlined in 3.3.7 are not successful then this design may well take its place. With the addition of a background that subjects may be familiar with this design may prove to be useful.

3.3.3 Sphere

A similar black and white striped sphere was produced with the patient "positioned" in the inside of the sphere. The sphere could then be set to roll, pitch and yaw at different speeds and angles. While the possible combinations of roll, pitch, and yaw angles and speeds are large in number thus giving a wide scope for identification, the number of useful combinations of these is restricted; furthermore, World Up had problems with linking the stripe pattern successfully at the top and bottom of the sphere hence this design was discarded.

3.3.4 Changing pattern

Consultation with appropriate medical personnel led to an idea that by creating a non-uniform block pattern similar to Figure 11 and projecting the continuous motion of such a pattern in the periphery of the visual field might lead to postural instability and eventually, motion sickness. Given the limited field of vision that the HMD obtained for these tests it was decided against using this strategy however, should an effective method of applying a visual stimulus that allows for a wider field of vision is found then it is likely that this strategy may be incorporated into such tests.
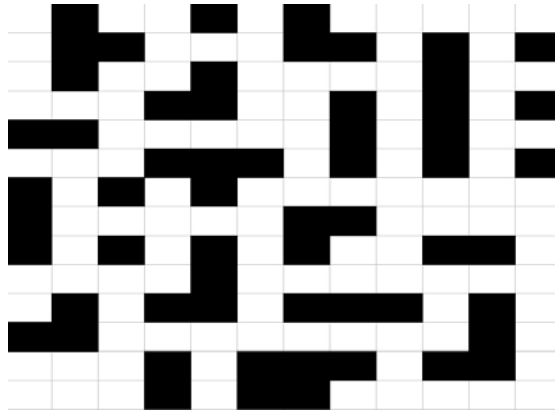
Figure 11 - Non-uniform "blocks" pattern

3.3.5 Project a video of moving images onto HMD

A similar technique was used in [23] whereby a feature film was played on the HMD and subsequent postural response was measured. The problem with this idea was that while it would be simple to ascertain motion sickness of the subjects, difficulty would certainly arise in identifying particular speeds and orientations of the video projection.

3.3.6 Computer game technology

Many computer games are known to be "immersive" in their nature, thus the idea was formulated that by playing a video game sequence through the HMD a postural sway might thus be elicited and measured as in [22]. The shareware game Racer, as seen in Figure 12, was identified as a viable game to be used.

Figure 12 - Racer computer game

As seen before, the limiting factor in this design is the lack of quantifiable data obtainable from the game environment and while and interesting experience for the subject under test it is rendered invalid for the purpose of posturography and subsequent identification. Unlike [22], where postural response was measured before and after immersion in the computer game environment; for the purpose of these tests, whereby it is required to measure the postural response simultaneously with the use of the virtual environment it is impractical to instruct a subject to play a video game whilst standing on a force platform.

3.4 Final Design – Vertically Rotating Cylinder

As may be seen from Figure 13, the final design was chosen as a black and green vertically rotating cylinder set against the back drop of a blue sky. The green was chosen as attempts to use black and white resulted in the HMD being unable to present the white colour clearly. It was seen that, at certain speeds, the white stripes became a mix of red green and blue. Use of the green instead of white alleviated this problem, furthermore green is a colour widely used in a medical environment when the requirement is to calm and reassure subjects, hence this choice was made above red or blue.

The surrounding sky was added to give the subject a static reference point while the cylinder rotated such that the feeling of motion would be accentuated by seeing the relative motion of the cylinder and sky. In addition to this, rather than adding a single block colour as a background, the sky pattern gives the subject something familiar in the field of view thus the appropriate blend of cognition and quantifiable stimulus is achieved.

The environment was programmed such that the speed (deg/s) could be increased or decreased by a single unit using the "↑" and "↓" keys. The cylinder could also be made to increase or decrease roll and yaw angle simultaneously by a single unit using the "←" and "→" keys.
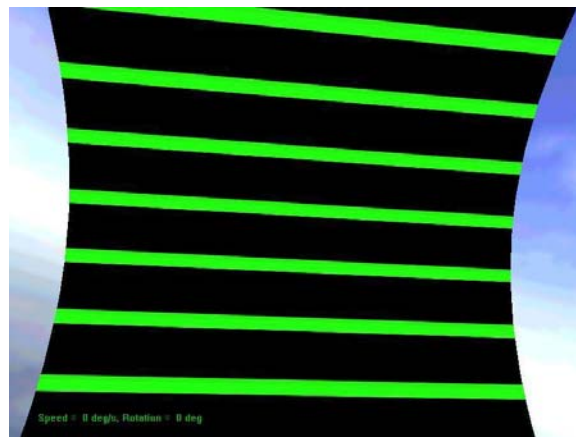
Figure 13 - Final Design – Vertically Rotating Cylinder

The requirement also arose to be able to carry out step tests so and additional level of functionality was incorporated that allowed the cylinder to be set to a given rotation at a single key press: ±10, 20...90 (See Appendix for Key Press list). A key press was also added to bring the cylinder to an immediate rest in its zero-vector position. In this manner, the VOR could be suddenly charged with the image of a cylinder rotating at a given speed; and once charged the cylinder could be stopped and the resulting postural sway examined.

For less sudden charging of the VOR, a series of positive and negative ramp functions were also added. The cylinder could be set to accelerate to a given speed (±20, 40...120) in approximately 9 seconds and then stopped suddenly. This would allow

analysis of the effects of slow charging and sudden discharging of the VOR on postural stability.

It should also be noted that the final intention for this software is for use in a posturographic pilot study, thus a further requirement was that each set of data was individual to a given subject. The force platform software, PostCon, registers patients according to name and *personnummer* (see Glossary) thus, the same level of functionality was added to the World Up simulation with appropriate tags to identify between the cylinder measurements and the viewpoint measurements.
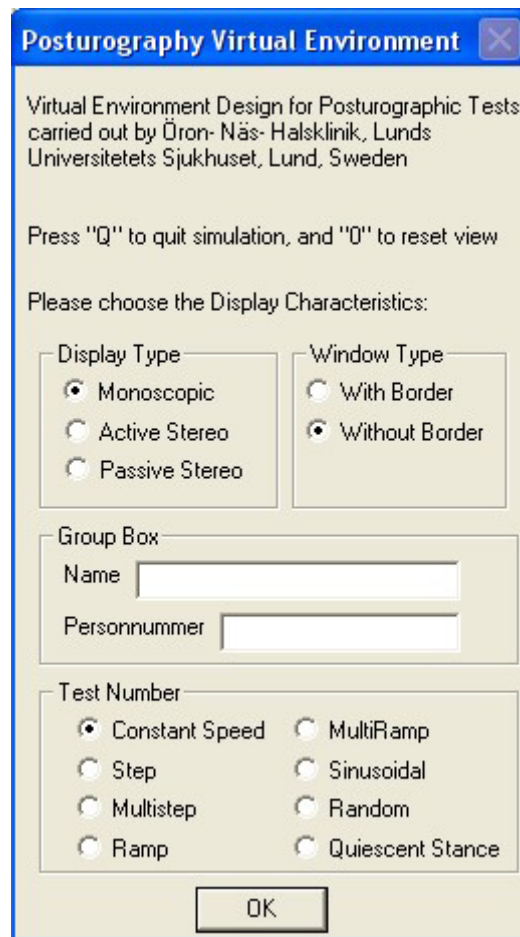
Figure 14 - Graphical User Interface for Virtual Environment used for tests

As may be seen from the graphical user interface in Figure 14 it is anticipated that results will lead to the necessity of introducing a variety of test patterns hence these have been added into the GUI in readiness for this. Furthermore, functionality has been added to allow for improved HMD or other display varieties.

3.5 Extracting Data from the Virtual Reality environment

In order to be able to perform System Identification on the standing human using a visual stimulus it is necessary to be able to quantify what the subject sees through the HMD. Using the World [7]Up scripting language it was possible to write scripts that gave the rotation and translation coordinates of both the rotating cylinder and the position of the "Flock of Birds" in addition to a time reference and the basic speed of rotation. The translation of the head is a 3D vector coordinate measurement and the rotation is given by a 4 component quaternion measurement. From this a relative measure of the rotation of the "Flock of Birds" and the cylinder may be achieved.

Using the quaternion data, a time varying rotation matrix could thus be constructed as follows:

If $Q = q_0 + q_1\mathbf{i} + q_2\mathbf{j} + q_3\mathbf{k}$ (sometimes represented as $Q = q_0 + q$, where q_0 is the scalar component and q vector component), then define a rotation matrix, R, as follows (See [12]):

$$R = \begin{bmatrix} q_0^2 + q_1^2 - q_2^2 - q_3^2 & 2q_1q_2 - 2q_0q_3 & 2q_1q_3 + 2q_0q_2 \\ 2q_1q_2 + 2q_0q_3 & q_0^2 - q_1^2 + q_2^2 - q_3^2 & 2q_2q_3 - 2q_0q_1 \\ 2q_1q_3 - 2q_oq_2 & 2q_2q_3 + 2q_0q_1 & q_0^2 - q_1^2 - q_2^2 + q_3^2 \end{bmatrix}$$

For the purposes of preliminary analysis the basic rotation speed of the cylinder was recorded as well as the duration of each frame. The frame duration, as will be explained in the next section, was taken such that a record of the "sampling" frequency of the simulation might be made. This would be of use for any subsequent resampling of the data that might be required.

3.6 Real Time Issues

One of the most difficult issues faced in this project was finding a way to integrate the use of PostCon, the existing software used to control induced postural disturbances and measure subsequent sway with the virtual environment such that the simulation software and PostCon begin and end measurements at the same time. A further problem is the non-uniform rendering rate. Given the script based nature of World Up, during the simulation, the software runs through each script and then renders a new frame. The speed at which a new frame is produced is non-uniform, which gives the need for statistical interpolation between the measurements of the force platform and the data outputted from the virtual reality environment.

One of the problems with the World Up software that while it allows for the maximum time taken for rendering to be set, it does not allow for a minimum and as yet there are no indications that this is possible. It is clear that such real-time computing issues are beyond the scope and considerations of this thesis however, it is hoped that eventually both the force platform software and World Up software will

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[7] World Up is a product of Engineering Animation Inc. (www.sense8.com)

not only communicate but also allow for the same sampling time of the force platform software and the virtual environment to be the same. Currently, preliminary tests have shown the rough sampling time (inverse of the frame duration) to be around 80Hz (See Figure 15) so this has been set as the sampling time for the force platform recordings.

While these issues are being resolved it is hoped that more approximate methods of measuring response relative to the motion of the cylinder in order to carry out system identification. These real time issues should by no means get in the way of ascertaining further knowledge of the effects of visual stimulus on the human postural control system.
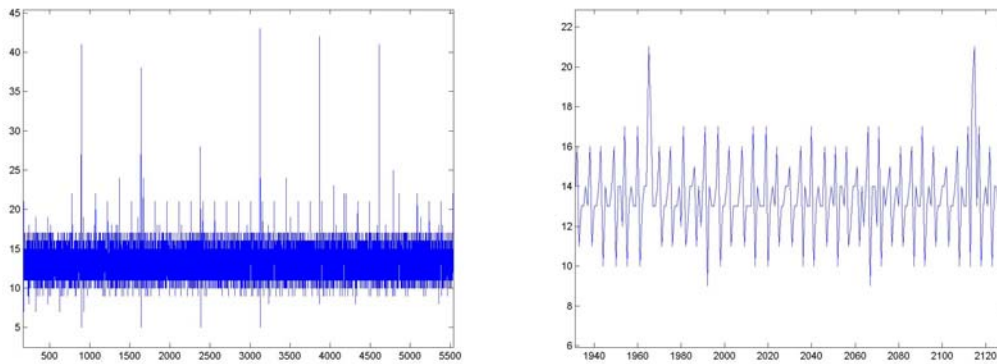
Figure 15 - Example of the non-uniform frame duration pattern of a World Up simulation

One of the suggested methods of creating a pseudo-synchronisation was to create artificial markers in the test set that would mark out the beginning and end of the tests. By asking the patients to simultaneously turn their head left and lean as far forward as possible when the test began and again when the test ended a reference point in the data set could be achieved.
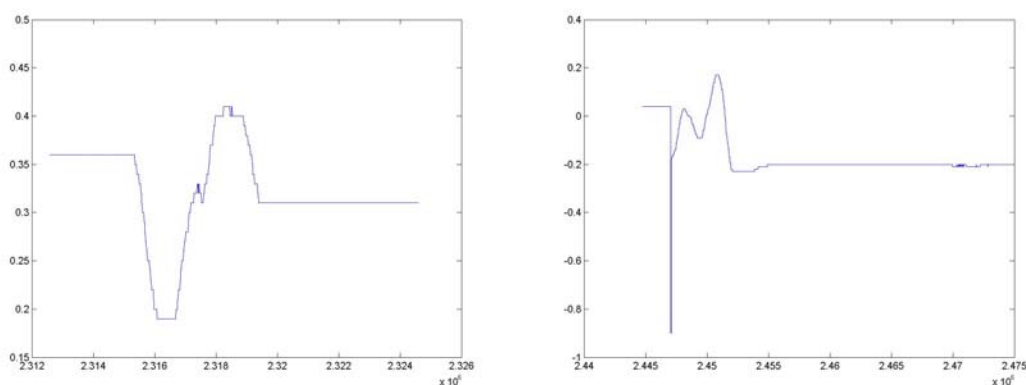
Figure 16 - Data recording of patient looking Left: Left and Right; Right: Up and Down

The leftwards direction was chosen since, as may seen in Figure 16, it is an easily identifiable movement within the recording and not one that would be used for the identification process itself.

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3.7 Test Patterns

A further consideration is the test patterns that should be used during the tests. As mentioned before, this manner of assessment has never been carried out before and as such it is uncertain what will produce the right effect. Despite this it is felt that similar methods to that used in system identification of physical systems should be used; this means that step, ramp and sinusoidal input sequences with respect to the rotation speed of the cylinder.

It should be noted that the step and ramp functions are relatively simple to implement, however, the sinusoidal input may prove more difficult and will be left out of this study. Furthermore, in many system identification experiments, as in section 4, a pseudo random binary signal is used as an input signal; clearly to alternate between two rotation speeds in a random binary fashion would have little or no effect on a subject's postural stability. This is due to the fact that for there to be an effect on the postural stability of the subject, there must be at least a six seconds delay between each change in speed to allow the velocity storage mechanism of the eye to adjust to the new speed and the vestibulo-ocular reflex to register the need for any postural adjustment. Such a low frequency negates the use of a PRBS; instead a series of steps from zero to a particular speed, both forward and backward rotation, will be attempted.

As part of this Master Thesis, analysis around which speeds and directions of rotation are effective at producing postural sway will be carried out. Once these speeds and directions have been broadly identified, a more concentrated study may be carried out.

Part II: Initial investigation into the use of Virtual Reality in Posturography

4.0 Initial Investigation into viability of using VR

Before a fully designed virtual environment should be implemented it makes sense to see whether there is any basis for using a virtual reality solution to the visual stimulus problem at all. In order to verify this, a crude series of experiments were carried out, these are described in the following sections:

The initial problem posed was how to test the viability of using VR to apply without having a fully designed environment. The solution devised was to test the response of the subjects to the three possible visual conditions (eyes open fixed stimulus, eyes closed, eyes open changing stimulus) in the presence of other stimuli. In the case of the changing stimulus this was applied simultaneously with another stimulus. The other stimulus in this case was chosen as a vibratory stimulus applied to different muscle groups as explained in the next few sections.

4.1 Materials

Postural performance was measured according to the force actuated by the subjects feet on a custom built platform (400*400*75mm) equipped with strain gauges. The vibratory stimulus was generated by a revolving DC motor equipped with a 3.5g eccentric weight at one end. The vibrator, as may be seen in Figure 17 was built into a metal cylinder 50mm long and 18mm in diameter. The frequency and amplitude of vibration was controlled by varying the input voltage of the DC motor.

Figure 17 - Mechanical Vibrators

The visual stimulus was applied using the Cy-Visor DH4400-VP Head Mounted Display. The image shown was that of a horizontally rotating cylinder similar to that show in Figure 9.

4.2 Methods

The cylinder was set to rotate at 51deg/s; crude tests showed this to be a sufficiently disorientating speed. The visual image, when used, was applied simultaneously to the vibration pattern. The vibration pattern used was of 1.0mm amplitude and 85Hz frequency turned on and off according to a pseudo-random binary pattern such that the subjects were unable to predict when the next set of vibrations was due to occur. The subjects initially underwent a 30 seconds period of unperturbed quiescent stance before the vibration stimulation period began. The stimulation period was 205 seconds.

4.3 Experiments

In previous posturographic experiments galvanic, vestibular and mechanical vibration stimuli have been used on the gastrocnemius muscles of the calf and the upper trapezius muscles. It was proposed that a series of tests were to be carried out using the mechanical vibration stimulus (See Figure 17 below) on the gastrocnemius muscles, the neck muscles and also the lower back muscles as part of a general broadening process for the posturographic tests. It should be noted that due to technical difficulties, no auditory stimulus was provided for any of the orientations.

The test set was chosen as follows (See Figure 18 and Figure 19 below for equipment orientations).

1. Calf Muscles
    - Eyes Open and fixed on a point on the wall
    - Eyes Closed
    - With Head Mounted Display (HMD)
2. Neck Muscles
    - Eyes Open and fixed on a point on the wall
    - Eyes Closed
    - With HMD
3. Back Muscles
    - Eyes Open and fixed on a point on the wall
    - Eyes Closed
    - With HMD

Figure 18 - Orientation of the Vibratory Stimulus with respect to the neck, calf and back muscles
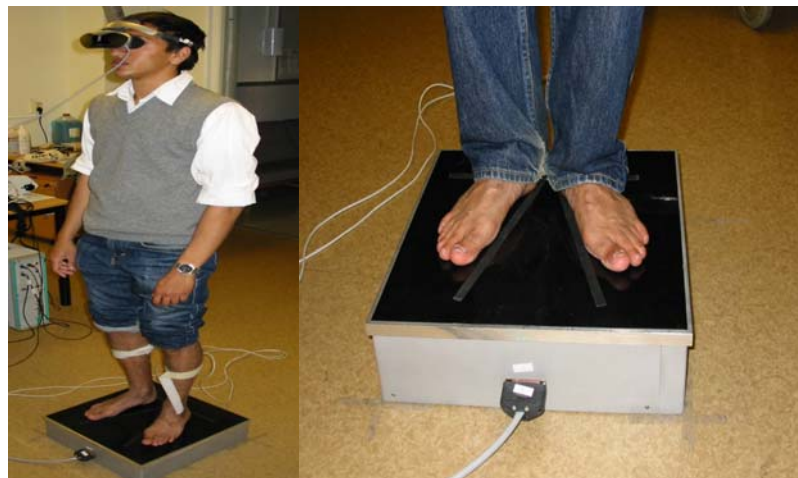
Figure 19 - Orientation of VR goggles and Feet position

This order was chosen in order to minimise the time duration of the experiment set and the complexity for the subjects.

10 healthy subjects (5 male, 5 female, Age: (Range: 20-33) (Mean: 23.7)) were selected to take part in the tests. All of the subjects were naïve to the nature of the tests. It should be noted that one of the female subjects was unable to complete the test due to a sudden and unexpected illness; a further subject was discovered to be an agoraphobic and was thus excused from taking part in the tests, the data collected on this patient was discarded.

4.4 Results

In the following sections the output response of a single subject is presented (4.4.1) following which the identification work using ARX and subspace based identification (4.5.2). The main tool used to analyse the data was the Matlab System Identification toolbox. ARX modelling followed by model reduction to third order models and Sub-spaced based identification using the N4SID algorithm were the methods used for Identification.

4.4.1 Output Response Data

The first step in analysis is to look at the input-output for a given stimulus and orientation. The software used, PostCon, is able to extract force and torque data from the force platform in the lateral, Anterior-posterior and "upward" directions. Given that the mechanical stimulus was intended to act in the anterior-posterior and the visual stimulus, a rotating cylinder (see Figure 9), which acted in the lateral plane analysis was carried out on responses in these two planes. The results of experiments carried out on the calf, neck and back muscles of a single subject are thus presented below. The input signal was taken as the PRBS mechanical vibration signal and the output signal was taken as the torque response in the anterior-posterior plane and the lateral plane.

From the graphs below in Figure 20 - 28, it may be seen that the least response in both planes is gained from the subject standing with open eyes. For the closed eyes orientation it may be seen that the patient's torque response in the anterior-posterior plane, after an initial transient phase, settles around a non-zero mean value. This phenomenon has been termed adaptation and may be explained by the patient becoming used to the stimulus and anticipating its action. No such adaptation patterns can be seen in lateral plane for any of the visual stimuli however, the response appears to be more erratic for the eyes-closed and VR orientations with the VR the most erratic of the three.
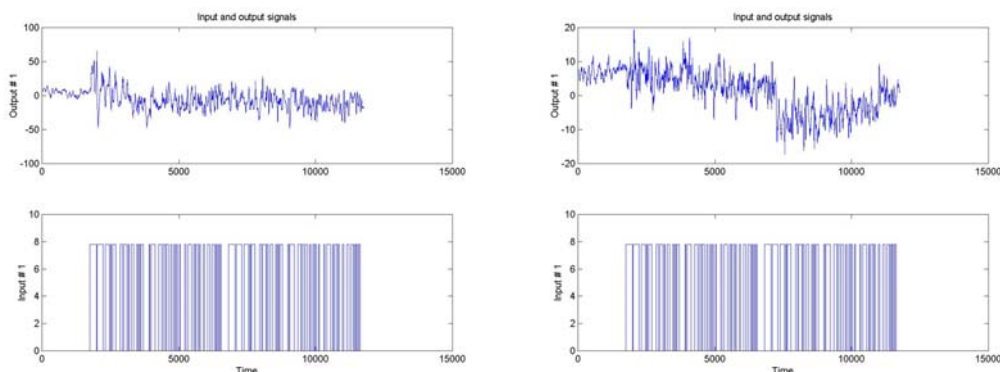
Figure 20 - Response in Anterior-posterior and Lateral Planes for "Eyes-closed Calf" Stimulation
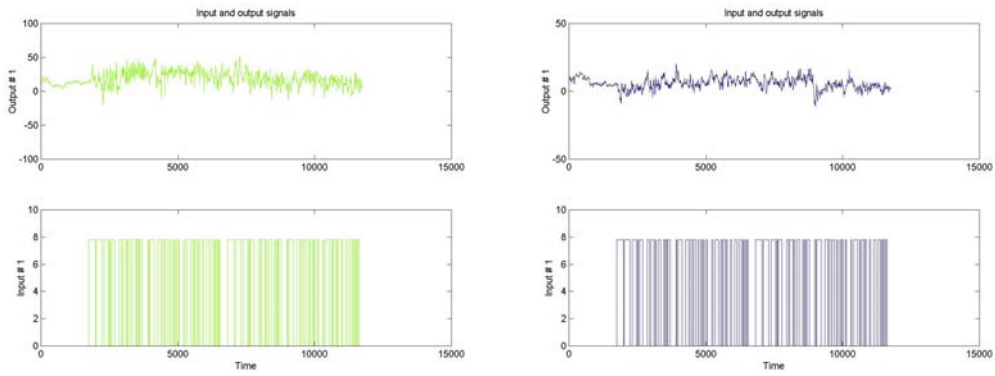
Figure 21 - Response in Anterior-posterior and Lateral Planes for "Eyes-open Calf" Stimulation
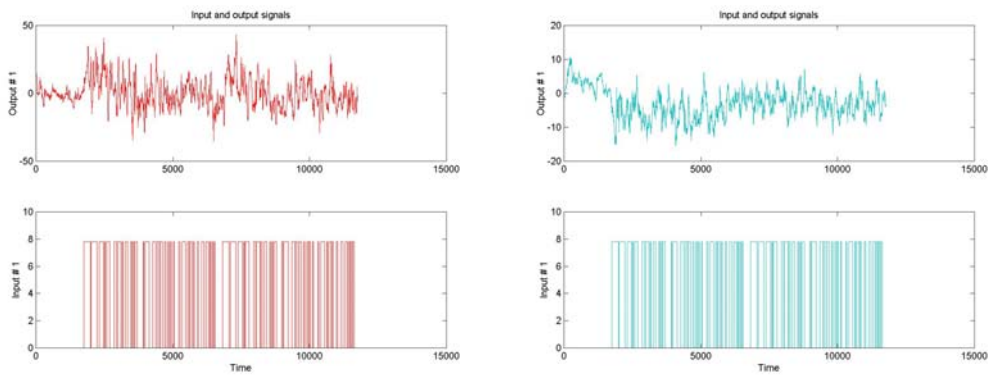
Figure 22 - Anterior-posterior and Lateral response for "VR Calf" Stimulation
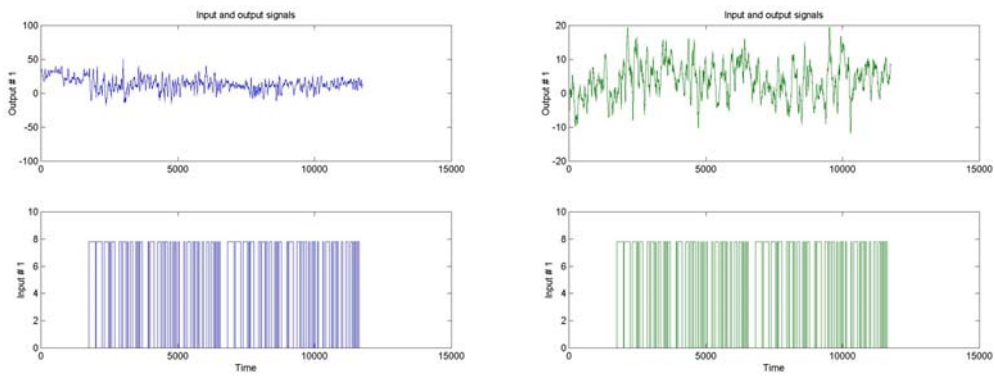
Figure 23 - Anterior-posterior and Lateral response for "Eyes closed Neck" Stimulation
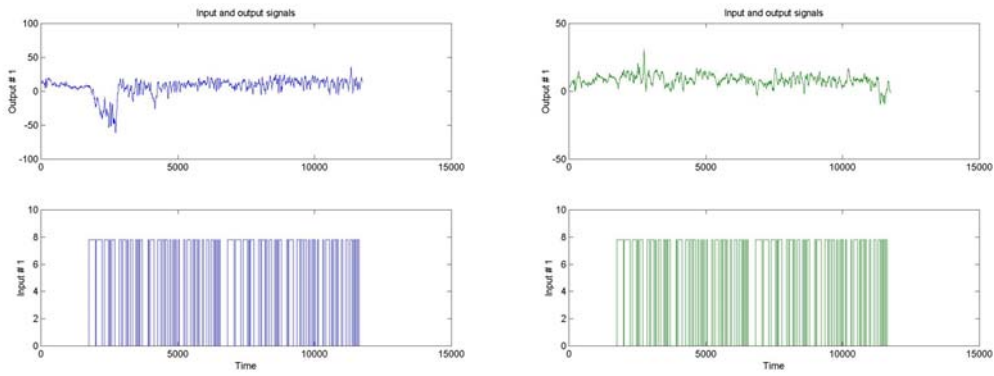
Figure 24 - Anterior-posterior and Lateral response for "Eyes open Neck" Stimulation
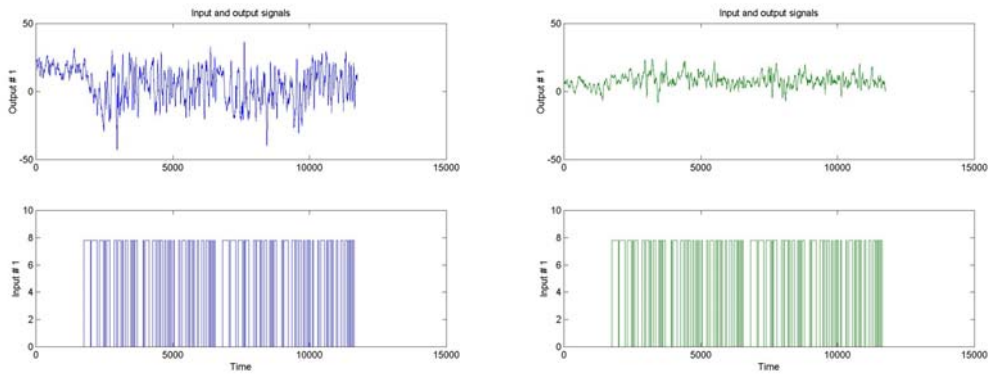
Figure 25 - Anterior-posterior and Lateral response for "VR Neck" Stimulation
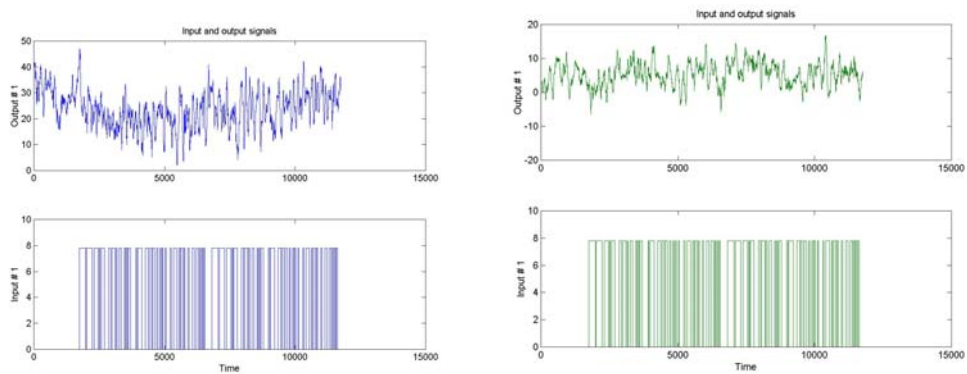
Figure 26 - Anterior-posterior and Lateral Response for "Eyes closed Back" Stimulation
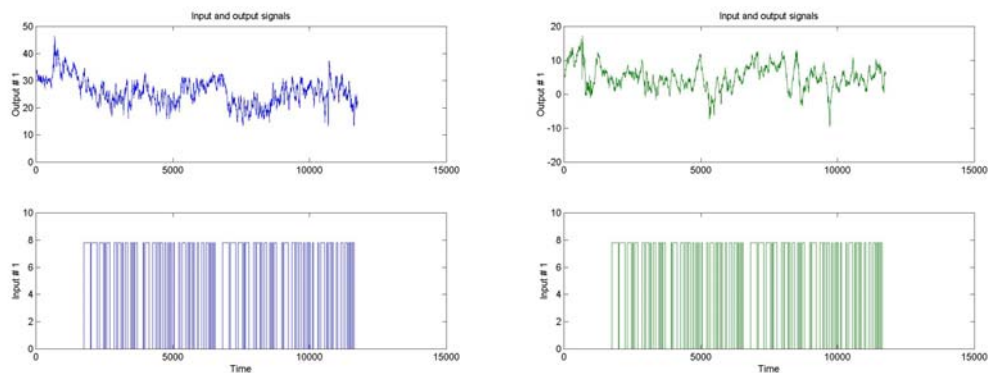
Figure 27 - Anterior-posterior and Lateral Response for "Eyes open Back" Stimulation
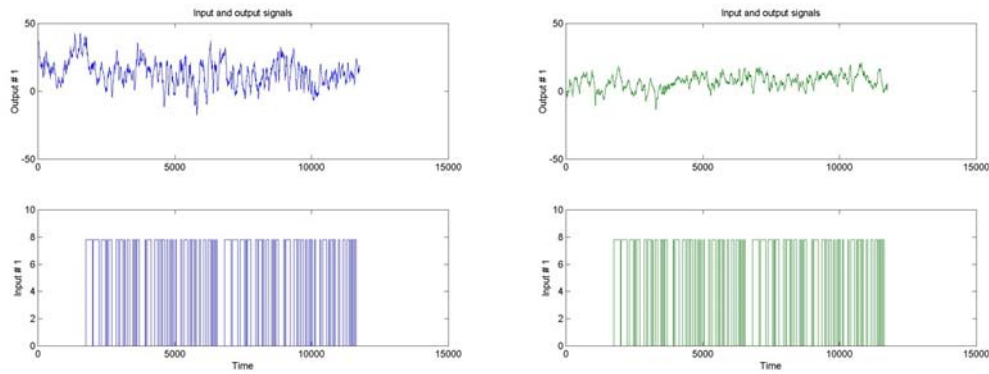
Figure 28 - Anterior-posterior and Lateral Response for "VR back" Stimulation

From the response data the case for further analysis into the use of dynamic (changing) visual stimulus is clear however; equally obvious is the need to carry out system identification on the crude data obtained during these experiments. Identification carried out on this data gave a clearer idea of how different the models for each orientation are formed.

4.5 Identification

The starting point for analysis with respect to signal processing is to examine the coherence functions of the data. The coherence functions depicted were created with the PRBS stimulus as the input signal and the anterior-posterior torque ("sway") and also the lateral sway. As may be seen from Figure 29, 30 and 31, none of the orientations give input-output coherence properties that indicated the possibility of linear modelling for any frequency range. This is partially due to the fact that the postural control system has a natural feedback response with the control system acting to counteract any stimulus and maintain upright stance resulting in poor coherence properties (See Figure 32).

It is essential to note however, that coherence function analysis, applied piecewise on input-output data, is only an initial part of identification and poor results should not invalidate the need for more detailed analysis. It may further be suggested that there may be a discrepancy between the frequency of the PRBS vibration stimulus and the frequency with which the postural control system reacts; this further highlights the overall non-linear nature of the postural control system.
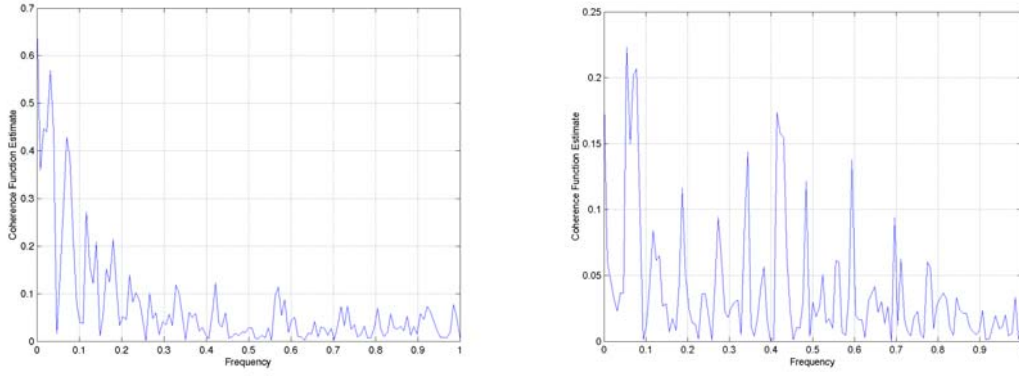
Figure 29 - Coherence function for Anterior-posterior and Lateral Sway for the "Eyes-open Calf" set up
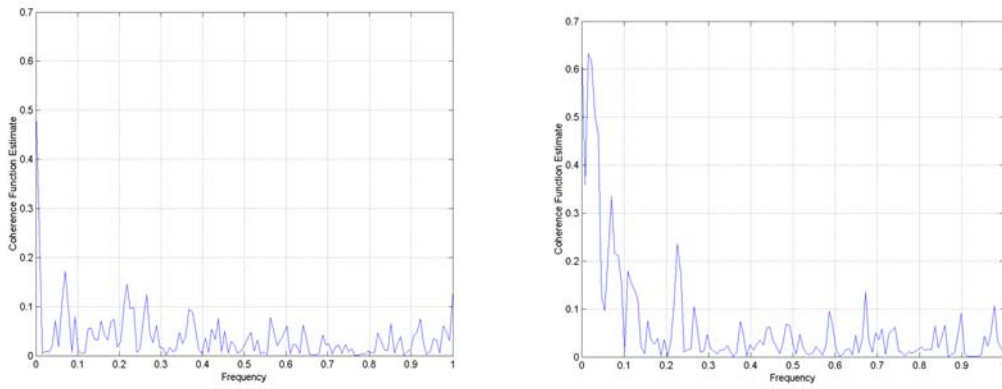
Figure 30 - Coherence function for Anterior-posterior and Lateral Sway for the "Eyes-closed Calf" set up
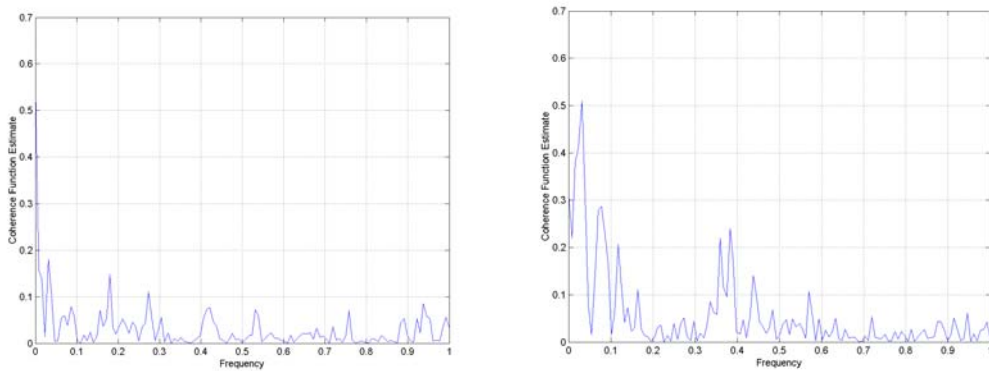
Figure 31 - Coherence function for the Anterior-posterior and Lateral Sway for the "VR" set up
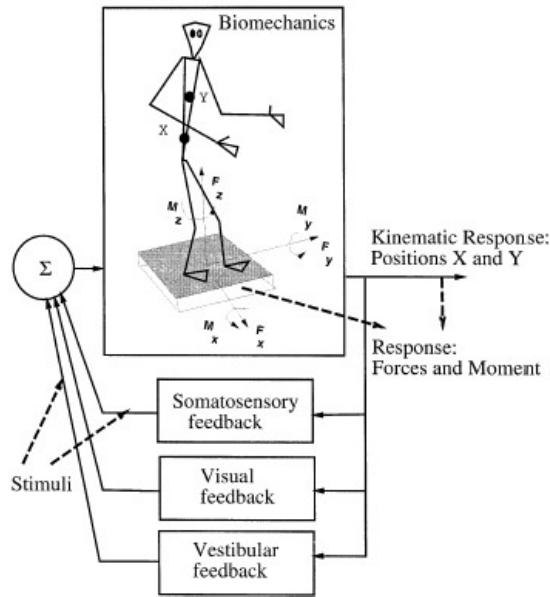
Experimental stimuli and response variables (3 forces, 3 moments, 3D position of two selected points.

Figure 32 - Multi-feedback nature of the postural control system

		Quiescent Stance		Vibration applied	
Mechanical Stimulation	**Visual Stimuli**	**Anterior-Posterior**	**Lateral**	**Anterior-Posterior**	**Lateral**
Calf	Eyes closed	19.949	3.0722	197.5707	35.8958
Calf	Eyes open	13.858	8.4055	114.9979	17.522
Calf	Virtual reality	18.6068	6.0887	123.5808	13.8055
Neck	Eyes closed	47.1619	19.3385	73.5054	26.0118
Neck	Eyes open	15.1862	6.947	178.8131	18.4644
Neck	Virtual reality	20.6243	12.6248	154.9749	20.7165
Back	Eyes closed	33.5214	10.755	49.9366	12.0914
Back	Eyes open	12.3602	17.884	15.9707	10.3777
Back	Virtual reality	78.4657	24.6214	85.4996	31.0141

Table 1 - Covariance function estimates for Quiescent and Vibration input data for torque responses in the anterior-posterior and lateral planes

From Table 1 above it may be seen in that for a mechanical stimulation being applied to the calf and neck muscles the covariance function estimates are, for the virtual reality visual stimulus, intermediate between the estimates for the eyes-open and eyes-closed visual stimulus. This trend is seen both in the quiescent stance period (before the vibration stimulus is applied) and also during the period where the vibration is applied. The same trend also exists between the anterior-posterior torque response and the lateral torque response. It is interesting to note that this trend is not repeated for vibrations to the back muscles.

4.5.1 Modelling: Auto-Regressive eXogenous ("ARX")

ARX[8] models are a subclass of the Auto-regressive Moving Average Exogenous (ARMAX) stochastic time series models. ARMAX models take the following form:

$$A(z^{-1})y_k = z^{-d}B(z^{-1})u_k + C(z^{-1})w_k$$

Where d is a time delay and A, B and C are polynomials in the backward shift operator. Modelling seeks to identify the coefficients of these polynomials. ARX models are a special reformulation of the ARMAX model into a linear regression model:

$$A(z^{-1})y_k = z^{-d}B(z^{-1})u_k + w_k$$

Where w_k is white noise.

As part of the identification process the Matlab[9] Identification toolbox was used to create high order ARX models. The raw data was taken and the trends removed; further more, the initial quiescent time period of the measurement was removed such that any transient behaviour was ignored. The data presented in this section is the response data for the mechanical stimulus applied to the calf muscles and as with the coherence function analysis the input signal used is the PRBS vibration signal.

It should be noted that during standard identification processes, a data set would be split into two halves. One section is used for the identification process and the other is used for the validation process. This is so that analysis may be carried out on the model created and not on one particular set of data however, as stated earlier, this would prove inappropriate for the data from these experiments which saw a slow "parameter" change during the adaptation process.

The model reduction process took place in three phases. The higher order ARX model yielded by Matlab was first converted from theta format to state space format. Using the state space format, the balanced realisation was formulated (see Appendix for code used). By inspecting the singular values, the amount that the model could be reduced by was ascertained. The appropriate reduction was then carried out. The reduced order state space model was then converted into a transfer function representation from which the final continuous time third order system was produced. The denominator coefficients were then equated with the η, k and ρ values in the following equation:

$$s^3 + \eta s^2 + ks + \rho$$

η = Stiffness
k = Swiftness
ρ = Damping

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[8] For more information on ARX and ARMAX modelling consult [2]
[9] Matlab is a product of The Mathworks, Inc

As shown in the introduction this is the representation of the human postural control system.

Table 2 below shows the results obtained for one of male subjects. It may be seen that it was not possible to produce a definitive result for two of the experiment sets. This was due to the fact that the discrete time models contained unstable poles, thus the order of the denominator had to be increased to accommodate this leaving a fourth order continuous time polynomial thus it is not possible to equate the appropriate coefficients.

Muscle Group	Visual Orientation	Stiffness η	Swiftness k	Damping ρ
Calf	Eyes Closed	1.918	0.0182	0.007289
Calf	Eyes Open	0.8897	0.4716	0.1668
Calf	VR	0.3458	0.04026	0.001076
Neck	Eyes Closed	Unstable System	Unstable System	Unstable System
Neck	Eyes Open	0.4109	0.03906	0.0004012
Neck	VR	0.286	0.02654	0.0006554
Back	Eyes Closed	0.2559	0.7761	0.01976
Back	Eyes Open	1.105	0.3927	0.004054
Back	VR	Unstable System	Unstable System	Unstable System

Table 2 - Values of Stiffness, Swiftness and Damping for a male subject

Given that the model reduction was always set to reduce to a third order system, appropriate analysis of the singular values of the Gramian matrix would have shown that not in every case was reducing the model order to a third order system appropriate procedure. In certain cases, to do so would have meant a substantial loss in accuracy of the system however, in order to get an impression of stiffness, swiftness and damping this was necessary.
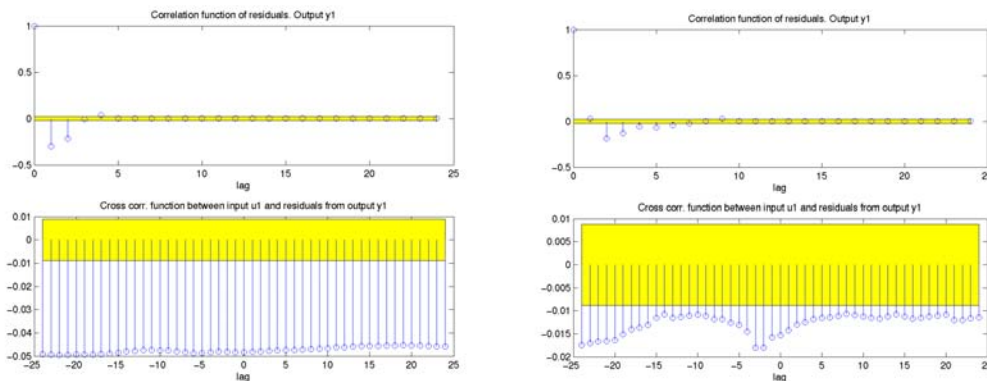
Figure 33 - Anterior-posterior and Lateral Correlation function of residuals for Calf open-eyes

A clear indication of this property may be seen from Figure 33 where by the correlation function of the residuals show that the parts of the data have been taken

into account for; it is suggested that an increase of model order would account for errant residual behaviour.

4.5.2 Modelling: Subspace Based Identification

A second form of analysis used was Subspace-based identification. The N4SID algorithm estimates models in state-space and returns them in the Matlab IDSS format. It is able to handle an arbitrary number of input and outputs. The state-space model is in the innovations form as follows:

$$x_{k+1} = Ax_k + Bu_k + Kw_k$$
$$y_k = Cx_k + Du_k + w_k$$

N4SID was run over series of model orders and the "best" order was returned. The algorithm decides the best model by examining the relative size of the singular values. It should be noted that the order given by N4SID is "best" according to the singular values and not necessarily the minimum order model achievable. In order to explore the possibility of a minimum order model using the N4SID, it was hoped that analysis could be carried out using the minimum order found from the ARX data analysis. This algorithm was run on all the data files for one of the subjects. Both forward-backward and lateral motions were analysed separately (4.3.2) and together (4.4). In general there was sufficient agreement between model orders between the "best" order prescribed by N4SID and the reduced order ARX modelling to warrant successful identification.
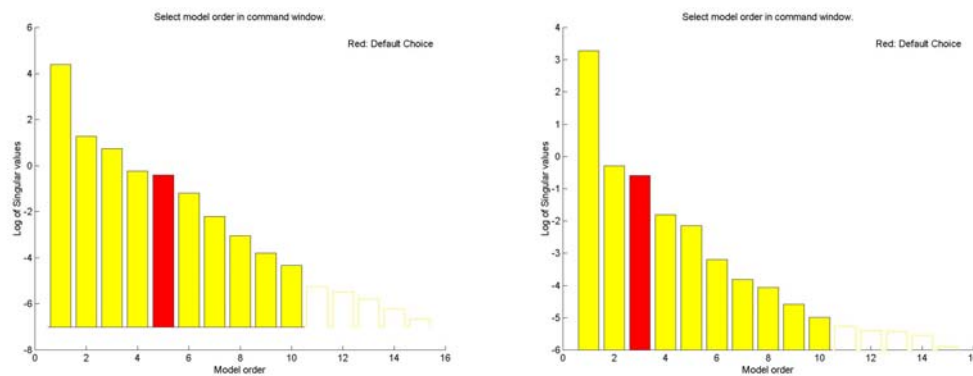
Figure 34 – N4SID model order selection for Anterior-posterior and Lateral response for Eyes-open Calf muscle orientation
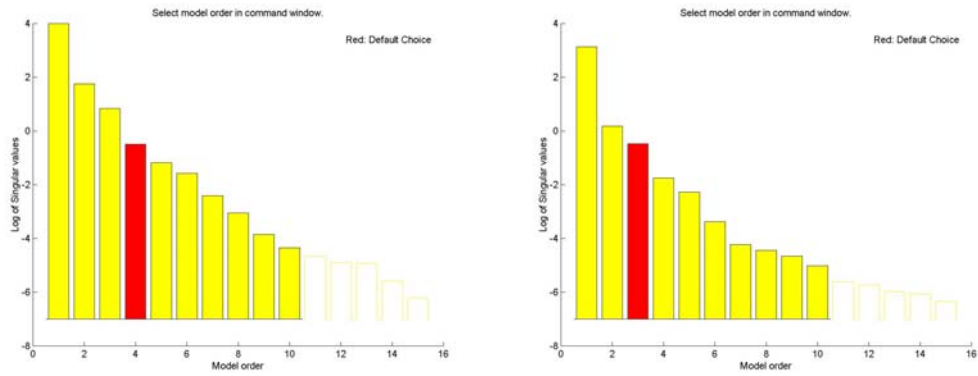
Figure 35 - N4SID model order selection for Anterior-posterior and Lateral response for Eyes-closed Calf orientation
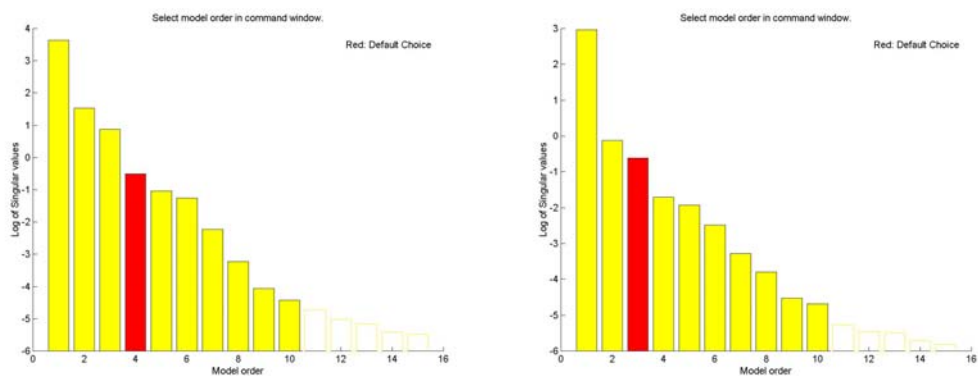
Figure 36 - N4SID model order selection for Anterior-posterior and Lateral response for VR Calf orientation

It is no surprise that the lateral analysis gives similar model orders in all cases given that the stimulus is not intended to be applied primarily in this direction. As may also be seen from Figure 34, 35 and 36 the model order for the open eyes orientation is higher than for the other orientation. This may be seen from the fact that one input and feedback loop is unaccounted for (visual stimulus) thus a higher order model is returned. The fact that a higher order model is not returned for the VR stimulus orientation may allude to the fact that further development has to be carried out on the virtual environment before significant effects are seen during the identification process. Similar result were recorded for the neck and back muscle experiments thus these results are not recorded here.

4.6 Validation

Given that there is a clear adaptation characteristic in subjects under test it may be suggested that one of the "parameters" of the human postural control system is changing as the length of time the stimulus is applied for increases. It is therefore required that an assumption be made before validation can continue. The assumption is made that two healthy subjects of the same sex and approximate height and weight would react in a sufficiently similar fashion that the taking the data from two such subjects, one subject's files could be used for identification and the other could be

used for validation however, ideally, the same experiment would be carried out on the same subject and the level of reproducibility from two test from the same patient wouldbe analysed. Thus the result from such analysis carried out on the models created with the N4SID algorithm may be seen below:
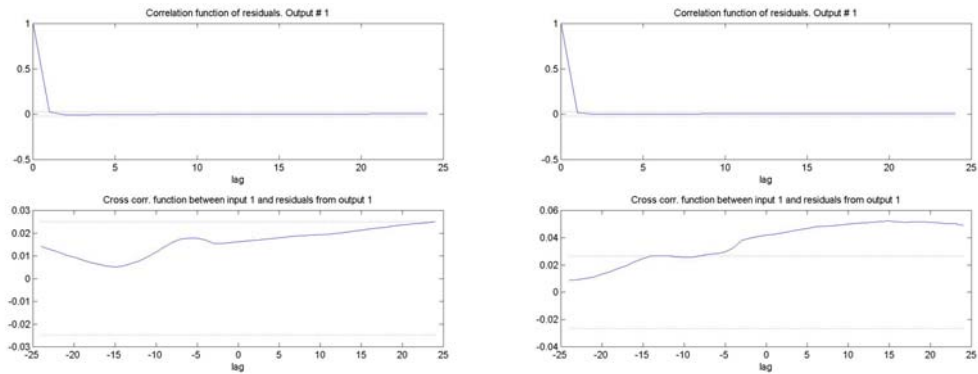
Figure 37 - Correlation function of the residuals for Calf open eyes orientation
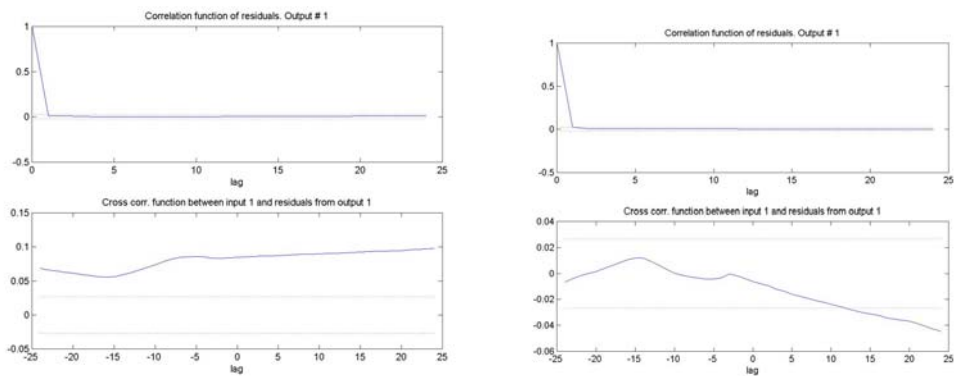
Figure 38 - Correlation function of the residuals for Calf closed eyes orientation
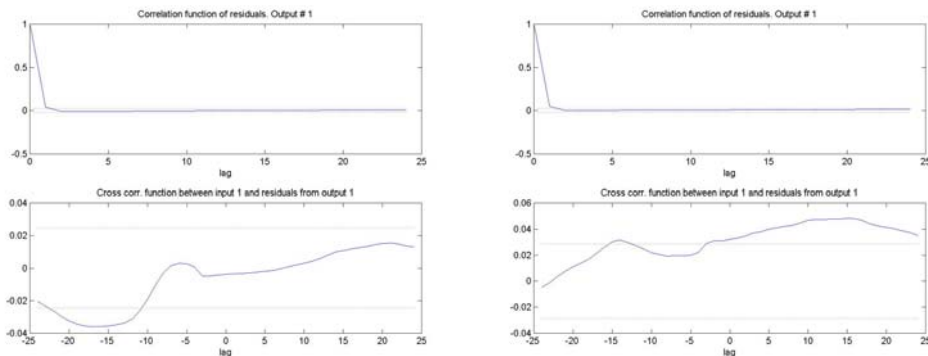
Figure 39 - Correlation function of the residuals for Calf muscles Virtual reality orientation

As may be seen in Figure 37, 38, 39 validation with the data of another subject gives excellent correlation and cross correlation properties however, in order for complete confidence to be achieved in the validation data it may be postulated that a second set

of data should have been taken from each subject. This is certainly a flaw in the assumptions but it must be recognised that given the number of experiments being carried out on each subject, to do each experiment twice would have at least doubled the time taken on each subject. This would clearly have made participating in the experiments less attractive to potential subjects to the point that the number of subjects taking part in the tests would have been very few.

4.7 Lateral Sway Analysis

Given the results above, and the fact that the ARX analysis focussed on the Anterior-posterior sway patterns a new approach to incorporate the lateral sway analysis is thus proposed as follows: to model the lateral sway response as an output error response given the hypothesis that for stimulus in the Anterior-posterior plane one would expect response to be in this plane.

It is unreasonable to expect that there would be no kind of response in the lateral plane however; it is reasonable to model this as an error in the system. It may thus be of interest to look at the system as an inverted conical pendulum capable of motion in two perpendicular, horizontal directions or a summation of these two directions. It should be noted though that, as with any physiological experimentation involving human subjects, although it is possible to create a general model from the subject or subjects under test it maybe seen that further experimentation with another set of subjects would reveal discrepancies in the model produced; essentially, no two subjects will react in exactly the same way.
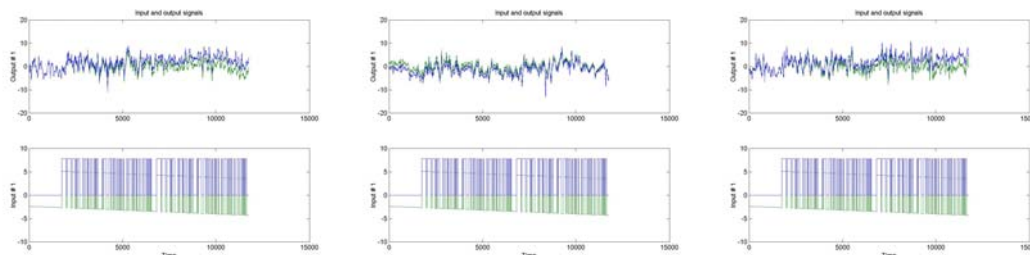
Figure 40 - Trends in Lateral response data

Figure 40 shows the three time series plots of the lateral analysis before and after trends have been removed. It may be seen there is no noticeable adaptation behaviour as is seen with the Anterior-posterior response in either the eyes-open and eyes-closed response however, the erratic response indicates further that a changing visual stimulus has a marked effect in the lateral plane and should be experimented further. This may be explained by the fact that the stimulus was a striped cylinder, which appeared to rotate around the subject thus causing the subject to sway in the lateral plane.

Furthermore it may be seen there is no noticeable adaptation behaviour in the lateral response it may thus be suggested that identification and validation may be carried out on two halves of the same data, response series. In order to create a model which allowed for a single input (PRBS signal) and two outputs (lateral and Anterior-

posterior response) the N4SID sub-space based identification algorithm was employed again. As with previous analysis, a selection of model orders (1:10) was specified and the N4SID algorithm returned best model.
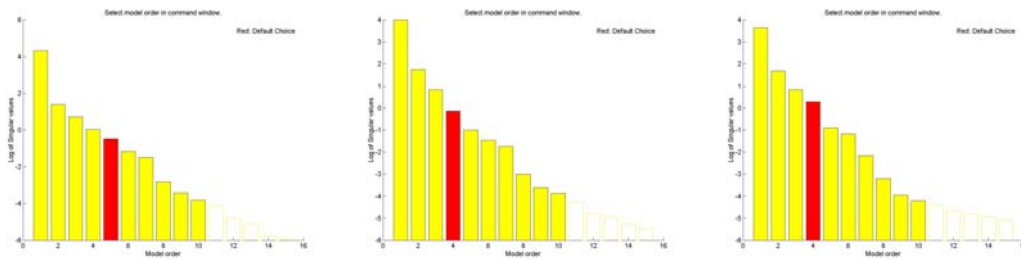
Figure 41 - Model order selection for N4SID algorithm for Calf muscles (Open, Closed and VR)
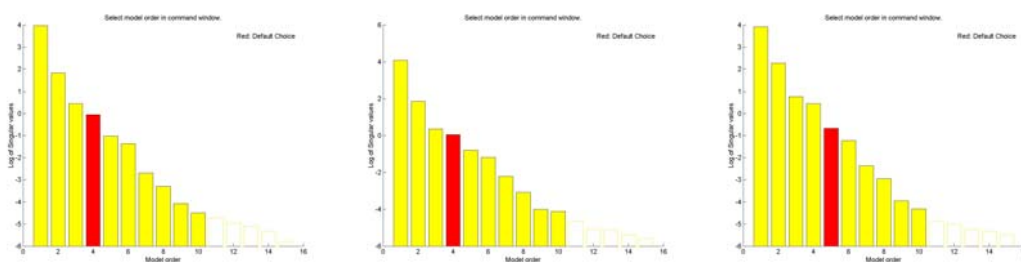
Figure 42 - Model order selection for N4SID algorithm for Neck muscles (Open, Closed, VR)
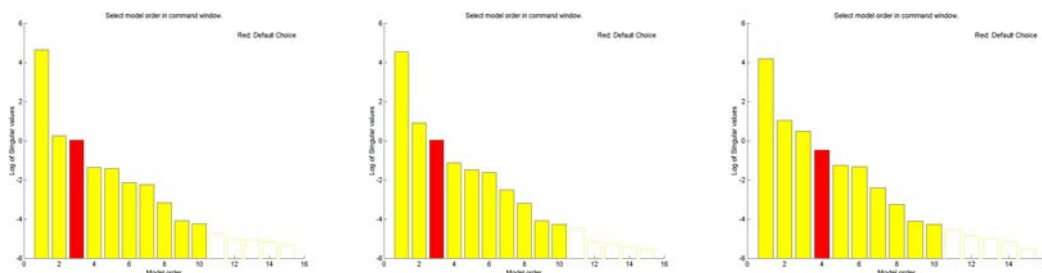
Figure 43 - Model order selection for N4SID algorithm for Back muscles (Open, Closed, VR)

As expected (Figure 41, 42, 43) the response with the eyes-closed orientation gives the lower orders, the fact is that in this case, with a mechanical stimulus the response is purely from the musculoskeletal system whereas in the other cases there is an input and response from the visual system, which is unaccounted for in the data set.

It was thought that further analysis could be done to determine whether or not the model orders suggested by the N4SID algorithm were indeed optimal. In order to do this is was required to take one of the higher order models and create a balanced realisation of this and then carrying out the appropriate model reduction subsequent to examination of the singular values. Attempts to create a balanced realisation of this output of the N4SID algorithm failed since the models produced were unstable. It should be noted that N4SID is based on the Lyapunov stability equation thus to use a different strategy, for example the Algebraic Riccatti equation may yield better results. This approach is beyond the level of this project however; it is certain to

receive appropriate attention in future identification work in the area of posturography.

4.8 Conclusions

From the series of experiments carried out a number of conclusions may be drawn:

From the difference between the responses between subjects tested with and without the virtual reality there is certainly basis for carrying out further analysis into the lone use of virtual reality as an input stimulus. It may be further concluded that the response seen from the use of virtual reality is "intermediate" between the use of an eyes-closed and eyes-open orientation.

From the data collected, it may be concluded that the adaptation patterns in the anterior-posterior plane seen in [7] have been successfully reproduced during these experiments. Although no adaptation as such occurs in the lateral plane, it can clearly be seen that the virtual reality has a similarly distorting effect to that seen in the anterior-posterior plane whereby the virtual reality gives an intermediate response between eye-open and eyes-closed.

N4SID as expected gives an increased model order for the lateral sway analysis however, the models produced are not stable thus it is not possible, given the algorithms used in N4SID to complete a balanced realisation of these models.

4.9 Discussion

As with any scientific process it is necessary to suggest ways of improving the experimentation methods for future use, in this case, with the experiments with the final virtual reality design in mind. Despite the fact that this project was intended to improve previous methods of work carried out, there still remain areas that could be improved and explored for further project work.

It was felt that the feet position used for the force platform experiments was an unnatural one and thus may have accentuated postural instability in those who already exhibited such behaviour. The use of a more natural feet position (See Figure 44) may require significant redesign of the force platform however this would be justified if it could be proven that more natural result were being obtained. Furthermore, it is understood that while allowing the subjects to stand in a more natural feet position would mean more realistic data, the experiments would loose one of the "standard" features of the test set.
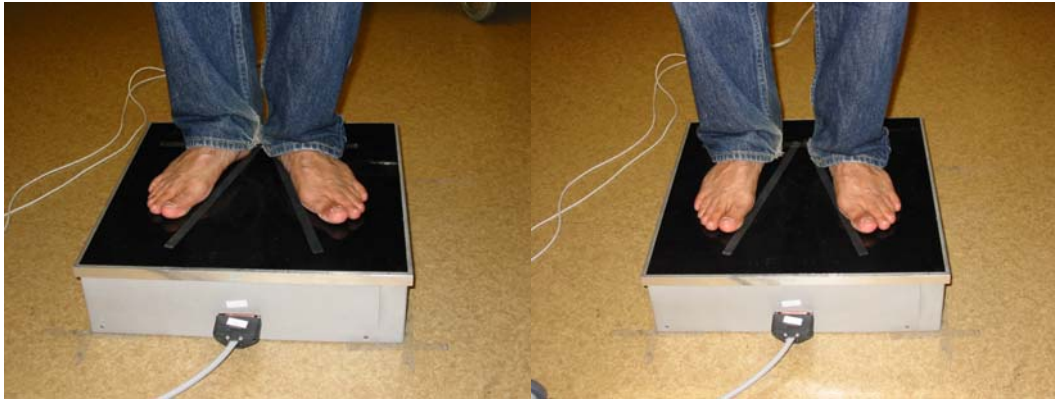
Figure 44 - Left: Current feet position; Right: Suggested "natural" feet position

As suggested in [1] the stimulation of muscle sets should not be restricted to the gastrocnemius muscles or the neck muscles. The muscles of the lower back region were stimulated however, it is suggested that perhaps the effects of the muscles of the upper back, upper legs and abdomen deserve consideration. A study would be justified whereby every muscle group considered to play a roll in maintaining upright stance was studying systematically with respect to mechanical stimulus.

A further suggestion would be to run the experiments carried out in this study on one subject in a random sequence in order to minimise the adaptation of the subjects' muscles and equilibrium to a particular stimulus or experience. It may be postulated that if a subject's muscles are exposed to a particular stimulus in one experiment, the muscles may become used to that stimulus thus rendering following experiments on that muscle group to become biased. It is recognised that although this may take more time, it is necessary to maintain thoroughness of procedure.

In order to be correct in the identification process, it is also suggested that the same experiments be carried out twice on the same subject such that one set of data may be used for identification and one may be used for validation. Besides this it is suggested that identification, in the case of vibration based experimentation, be split up into four parts:

- Quiescent Phase
- Initial Transient Phase
- Secondary Adjustment Phase
- Final Settled Phase

Furthermore, while the difficulty in identifying the relative effect of each stimulus and each response mechanism is recognised as considerable, it is felt that this would warrant further consideration in order to yield a greater understanding of the human postural control system.

In addition to this, it is suggested that analysis be carried out on the patients' quiescent stance in order to ascertain whether the subject has any noticeable characteristics to their normal stance that may appear as unexplained phenomena in the identification process. Identification could be made easier by improving the way the stimulus is applied. If an improved method of applying the vibration stimulus was

found such that it could be shown, as best as possible that the stimulus was being applied in the anterior-posterior plane then the suggestion that the lateral response should be modelled as an output noise would warrant greater attention. A further suggestion would be to use three vibrators on each leg, one positioned against the gastrocnemius muscle to act in the anterior-posterior plane and two to act on either side of the leg in the lateral plane. It is hoped that the two vibrators positioned in the lateral plane will cancel each other out and thus a more reliable anterior-posterior input may be obtained.

The visual stimulus used in these experiments was a crude prototype of more complex virtual reality environments being designed for use in posturography. It is hoped eventually that a measure of the rotation and translation of the cylinder as well as the rotation and translation of the head position may be recorded for use in identification. Subjects taking part in future tests will thus be subjected to a range of different cylinder rotation speeds and angles.

A further albeit informal hypothesis has also been postulated a result of this work: that those with experience with altering visual fields will have less of a reaction to the visual stimulus used in the experiments. This may be highlighted by an example: that someone with an interest in an outdoor activity, for example skiing, may have less of a reaction to visual stimuli than someone who does not get involved with such activities. A subject who is adept at skiing has experience of rapidly changing visual field and reacting correctly to them. It will thus be attempted to draw a correlation between the level of experience a subject has and the resulting response to the visual stimulus such that a range of "healthy" responses may be created.

Part III: Experimentation using Changing Visual Stimulus

5.0 Experimentation Using Changing Visual Stimulus

The following sections describe the experiments carried out using the virtual environment described in section 3.4. As explained previously, the results seen from this section will go forward to shape a future pilot study.

5.1 Setup

As with previous posturographic experiments carried out in the Department of ONH, Lund University Hospital, the force platform, Zebris, and PostCon software were used to measure postural instability. Two sets of experiments were carried out on each patient: a step test, and a ramp test. The step test involved rapid steps from zero rotation speed to speeds of up to ±90 deg/s (increments of 10 deg/s). The ramp test involved slow acceleration of the cylinder to speeds of up to ±50 deg/s (increments of 10 deg/s). In each case a rest period was used before any motion of the test began.

It was seen that previous tests the test duration was approximately 3 minutes however, for the purpose of these tests this was extended to 5 minutes allow for the full range of step and ramp functions to be tested. For each subject, two tests were carried out: one for step functions and one for ramp functions. This would allow for fast and slow charging of the VOR and response to be tested. Furthermore, the sampling frequency of the force platform measurements was chosen to be 80Hz as this best reflected the frame duration of the simulation in preliminary tests carried out.

5.2 Procedure

The potential subjects were first asked if they had any medical conditions, those with any such conditions were excused from taking part. It was explained that two five minute tests were to be carried out: a step test and a ramp test. The procedure of creating cues for later use in the identification process was demonstrated following which the necessary personal details were entered into PostCon.

Prior to starting the virtual environment the subject was fitted with the "Flock of Birds" device and the Head Mounted Display and then set to stand in the correct position on the force platform. The HMD was adjusted such that the subject felt comfortable and a clear image could be seen. This was done to ensure that the "Flock of Birds" was in the correct position when the virtual environment was started.

On start-up of the virtual environment the details of the subject were again entered in the appropriate fields. The subject was then instructed to stand upright but relaxed with hands by their sides, to look straight ahead and "concentrate" on the stripes on the cylinder (See Figure 45). Any other ambient light in the room was turned off so as not to distract the subject. The virtual environment was thus started with the cylinder at rest; PostCon was then started with the quiescent stance measurement setting selected.

Figure 45 - Subject under virtual reality test

The subject was then taken through the identification cue procedure. The first test to be carried out was the step test: using key presses the speed of rotation was set to rotate either forwards or backwards at a particular speed. Each particular speed was maintained for at least 8 seconds, to allow the VOR to charge, the cylinder was then brought to an immediate rest for another period of approximately 8 seconds. This pattern continued for 5 minutes, towards the end of the 5 minute test time a second identification marker procedure was carried out. The same procedure was then repeated but with the cylinder describing ramp accelerations instead of step patterns.

5.3 Results

Subject No.	Sex	Age	Interests and Activities	Observations
1	Male	31	Skiing	No great movement to either stimulus
2	Male	23	Weightlifting	Felt trembling in the legs during the test
3	Male	25	Computer Games (nothing physical)	Felt similar trembling to subject #2. Felt motion sporadically

Table 3 - First series of subjects

Having completed the first series of subjects and interviewed the subjects it was seen that the step stimulus was having little effect on the subjects. Furthermore, the subjects stated that they felt an effect from the ramp stimulus however, stated that the stimulus could perhaps either be applied for longer or up to higher speeds since little effect was felt at the slower speeds.

It was decided to keep the step test set however; the speed range for the ramp test was altered. The speed range of the ramp test was thus set at ±20, 40, 60, 80, 100, and 120. In addition to this, extra padding was added around the eye piece of the HMD in order to block out any ambient light. The results of these tests may be seen below.

Subject No.	Sex	Age	Interests and Activities	Observations
4	Male	25	Kickboxing (twice a week)	Little response to either stimulus
5	Male	37	Used to participate heavily in Karate (10 years ago)	Lots of movement to the stimuli but felt as though he didn't move a lot
6	Male	25	Football but nothing particularly regular	Felt "tired" after tests. Claimed to be effected more by the step test
7	Female	23	Nothing regular	Had an overall tendency to lean forward in the step test and to lean backwards in the ramp test but only felt sporadic notions of motion.
8	Female	24	Aerobics but not for at least 6 months	Felt sporadic sensations of movement in both the test sets

9	Male	22	Cycling	Noted that when fully concentrating on the moving stripes a sensation of motion was achieved but otherwise no feeling of motion occured.

Table 4 - Second series of subjects

From the results in Table 3 and Table 4 the following qualitative results may be stated:

Only two of the subjects had no response whatsoever to the visual stimuli. The remaining subjects either had physically abnormal reactions or sensations of motion.

Sensations of motion were at best sporadic. Although not mentioned by other patients the observation of subject #9 is perhaps the most pertinent: that sensations of motion were only achieved when fully concentrating on the motion of the stripes.

There were no patients who suffered any serious symptoms of nausea. The only indication of the onset of nausea would be the tiredness felt by subject #6 and subject #7.
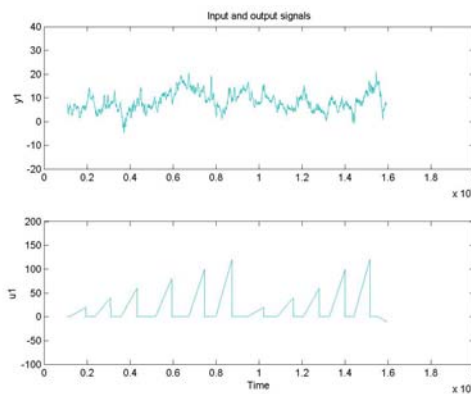
Figure 46 - Anterior-Posterior response of a subject to rotating cylinder undergoing ramp accelerations

From Figure 46 it may be seen that the postural response of the subject shows regions where the subject under test show response to the accelerations of the cylinder. Given that it cannot be confirmed that the subject was concentrating on the cylinder for the duration of the test, it is clear that no discussion can be carried out as to which speed and acceleration were most effective.

5.4 Identification

It is clear that only while subjects are concentrating on the motion of the cylinder can any postural response be induced. The rotation of the cylinder was intended as the input to the postural control system however, resulting postural response can only be judged according to the concentration pattern of the subject, which is undeterminable.

Given these observations, useful identification cannot be carried out. Identification may proceed if, and only if, a method may be found to either ascertain the concentration pattern of the subject or to ensure that the subject is concentrating for the whole duration of the test.

6.0 Discussion

Prior to laying out the conclusions of this study it is important to first discuss the limitations experienced during the planning and experimentation phase. This is done in order to place the conclusions within a wider context.

As mentioned in the experimental hypotheses (2.0) this is one of the first attempts to use virtual reality as an application in systematic identification of the human postural control system. It should come as no surprise if some of the hypotheses are proved wrong; from this the opportunity to formulate new hypotheses arises. As a result of this an initial difficulty arose in how to define a suitable environment that would stimulate the appropriate physiological sensors to elicit postural instability. Having done this a second difficulty was how to define an appropriate test pattern that could be used in the identification process; this had to be carried out with respect to "charging and discharging" of the VOR thus high frequency steps between speeds were rendered useless.

Perhaps the single biggest limiting factor in this Master Thesis was the Cy-Visor HMD. The HMD used was obtained prior to the outlining of this project and with only an idea of how such a project should proceed. It is widely known that the greater the field of view used in virtual reality the greater the opportunity for creating an immersive environment; this is due to the fact that a wider field of view the closer this is to the actual human field of view. The field of view for the Cy-Visor is limited to 31° degrees across the diagonal, visual displays exist that allow up to 60° degrees. It would perhaps have been better to first define the environment to be used and then to select and purchase a suitable display.

The lack of computer-based synchronisation between PostCon and the virtual environment means that the queues created by artificial exaggerated movement of the subjects; while obvious to identify are by no means accurate. Furthermore as was shown in the experimentation phase, the ramp test was the more successful of the input stimuli however, the important response came after the cylinder had been brought to a halt.

It should be mentioned that the environment was designed to elicit postural sway and motion sickness. Subjects who are aware of this immediately become sceptical about taking part, and despite best attempts to ensure subjects concentrate fully on the striped pattern for example by dimming any ambient light, subjects who begin to feel uneasy will tend to stop concentrating on the patterns and focus elsewhere on the visual field.

All of the subjects taking part in the tests were healthy and were selected on the basis that they would have no extreme reaction to the stimulus. This was due to the fact that the tests did not take place in the Vestibular lab of the Dept of ENT, Lund University Hospital as previous posturographic test, as in [1]; instead the test took place in the Re-flex Flexible Reality Lab, Ingvar Kamprad Design Centre, LTH where there were no medical staff on hand to assist should any subjects have had ill effects to the stimulus. The decision to move the force platform arose from the fact that attempts to run the virtual reality software in the hospital were blocked due to a network firewall

issue. The World Up software is required to access a remote site to access security codes that allow it to run; the particular network port that World Up requires is blocked by the network security in the hospital. As with any hospital, maintaining network security is considered to be of utmost importance such that to resolve such network issues would require consultation with high level administration staff and is at best unlikely hence alternative methods that will allow the running of the virtual reality software in the hospital are currently being considered.

There is an important psychological aspect of these tests that has not been discussed: the willingness of subjects to believe what they are presented with and the desire they have to allow the images to affect them. If the example is taken of an amusement park ride involving virtual reality; subjects enter into the ride willingly and with the desire to have an entertaining experience despite the fact that they are not totally sure what is about to occur. The effects of this are stark with the majority of subjects leaving with either a sense to being entertained or acute motion sickness.

It is clear that it is not possible to recreate the sense of unexpectedness of an amusement park ride in a medical test where subjects are first instructed as to the procedure and the relevance of the tests however, an altogether different approach may be required with respect to how the subjects are prepared for the test may be required such that better results are achieved. Greater analysis must be carried out to find a method or incentive that allows subjects to overcome the psychological aspects of these tests.

The fundamental difference between the experiments carried out in section 4 and section 5 is that in the case of the vibration stimulus used, the subjects had no control of whether the stimulus was applied or not. The vibrators were strapped to the muscle group under test and their vibration pattern was controlled by PostCon. In any event, the muscle group was under vibration until the test ended. In the case of the visual stimulus, the subject was given the instruction to concentrate on the motion of the stripes before the test began. There is no way of making sure that this occurs for those supervising the tests. The first instinct of any person who is subject to an uncomfortable experience is to take the necessary measures to stop the discomfort occurring. In this case, if a subject feels uncomfortable when faced with the visual stimulus, the tendency would be to focus on another part of the visual field away from where the visual field is being projected.

7.0 Conclusions

The findings made in this Master Thesis lead to the following sets of conclusions being made:

There is certainly basis for the use of virtual reality and the "vertically rotating cylinder" environment as a visual stimulus in posturography as has been seen by the sporadic perceptions of motion obtained by the subjects however; current environment and test procedure are not conducive to inducing motion sickness in the subjects.

The greatest factor that must be overcome is the psychological factor seen in the tests whereby subjects stop focussing on the motion of the cylinder thus rendering its effects useless. A way must be found of overcoming the psychological tendencies of subjects to look away from the rotation of the cylinder.

Advances must be made in the environment itself with respect to the sound adjustments being made within the environment and the motion patterns of the rotating cylinder if the environment is to be completely immersive. Experimentation must also be done on different methods of applying the virtual reality stimulus. It is thought that a Head Mounted Display with a wider field of view would be more effective in producing postural movement.

8.0 Further Work

Although work on this Master Thesis has a finite limit, work in this area will continue and as part of a scientific process it is useful to suggest possible avenues of exploration in future work. Many of these suggestions will be carried out by the Author in the coming months after this Master Thesis is complete.

As may be seen from the experiments carried out in section 5 each test incorporated motion of the cylinder in both the forward and backward directions. It is suggested that the number of tests be extended such that a single test involves rotation in a single direction. A study may the be carried out similar to those completed in section 4 whereby a calf vibration stimulus is applied as in previous tests and the response is measured with the cylinder rotating forward and the cylinder rotating backwards. Analysis may thus be carried out into whether the visual stimulus can have both an additive and subtractive effect to postural response. It is further suggested that an initial extended immersion period be carried out to allow the subjects to become accustomed to using the Head Mounted Display, in this way it is postulated that the virtual environment will be more effective.

In order to be able to test the virtual environment on subjects with degenerative postural control it is essential that appropriately trained medical staff be on hand should any patient have a severe adverse reaction. Considering this it is required that these tests are eventually run in a hospital environment. In order to achieve this either the requirement is either that the appropriate authorities be convinced of the importance of these tests and allow the relevant ports on the network to be opened or an alternative method of accessing the World Up security codes must be found. A more drastic solution would be to redesign the environment using another software package that does not require the use of internet based security codes.

As suggested in the discussion (6.0) one of larger obstacles of this work was the limited field of view that the Cy-Visor DH-4400VP allows. It is therefore suggested that, once the rotating cylinder environment has been fully developed, either a HMD with a wider field of vision is purchased or another method of applying visual stimulus be explored for example the projection of a moving image on to a wall that the subject would be set to face. The difficulty with this would be to block out any peripheral images to ensure that the subjects focus only on the visual stimulus. Projection of a visual stimulus on to a larger field to view would allow analysis to be carried out on both the centre of the field of view and the periphery.

Using the current virtual environment is planned that the cylinder be set to rotate in a sinusoidal pattern. It is hoped to prove the hypothesis that for a particular range of frequencies and amplitudes, subjects will exhibit a similar albeit delayed sinusoidal sway in the anterior-posterior plane. Besides this it is recommended that a longer experimentation time be used, perhaps up to 10 minutes, in order to analyse the required time of immersion before the onset of motion sickness occurs.

It is furthermore intended that the quality of sound pattern that accompanies the rotation of the cylinder is improve to incorporate the Doppler Effect such that if a subject rotates their head in a particular direction there is an appropriate change in

sound pattern. Besides this sound changes may be made for alterations in speed and rotation of the cylinder. The improvements in the management of sound will no doubt lead to a more immersive environment and thus clearer changes in the postural response. It may also be suggested that testing on subjects with full and partial hearing ability that are otherwise healthy may be tried. In this way an impression may be obtained as to how important the presence of appropriate sound is.

Having completed sufficient analysis with the environment used in this Master Thesis it is suggested that some of the other environments not used in the final experimentation also be tried. In particular, an environment should be used that allows for stimulation in the lateral plane similar to that seen in section 4. The eventual aim is to create a self contained software package whereby the virtual environment is embedded into PostCon for use in posturographic research. It is also hoped that analysis may be carried out on the movement of the eyes during the virtual reality tests such that the tracking behaviour of the eyes may be recorded.

The conclusions suggested that motion perception was achieved when subjects were fully concentrating on the movement of the stripes. A way of quantifying the behavioural pattern of subjects during the test, with respect to how much they concentrated on following the stripes should perhaps be explored. A simple paper questionnaire that patients could complete after the test to give those analysing the data an idea of how useful a particular patient's data might be.

Glossary

Given the non medical background of potential readers this section has to be fairly extensive:

VOR - Vestibulo-Ocular Reflex

Posturography – Measurement and analysis of posturographic response according to a given external input.

Vestibular - of or pertaining to the vestibule of the ear or its function as an organ of equilibrium

Proprioception - Any sensory structure which receives stimuli arising within the tissues (other, usually, than the viscera); esp. one concerned with the sense of position and movement of a part of the body

Retinal Slip – sensation that the retinal obtains as a result of the motion of an object under gaze

Vection - A visually induced illusion of self motion

Somesthesis - Pertaining to or designating those sensations (as of pressure, pain, or warmth) which can occur anywhere in the body, in contrast to those that depend on highly localized sense organs (as sight, balance, or taste).

Gastrocnemius Muscles – chief muscle of the calf of the leg.

Personnumer – Swedish National Identification number, 10 digits long, the first 6 digits are the subject's birthday; the last 4 digits are a random 4 digit number.

Acknowledgements

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Appendix

Explanation of force exerted by feet on the force platform
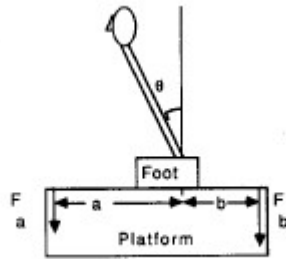
Fig. 6. Anterior force F_a and posterior force F_b on the force plate.
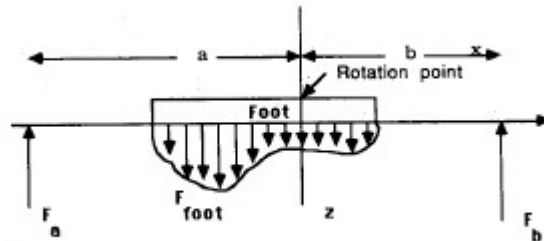
Fig. 7. Sole pressure F_{foot} on the area Ω of the force plate in the x, z plane.

From figure 6 (above) it may seen that a and b are horizontal distances from the point of rotation on the ankle to the supporting edges of the platform. Introduce Ffoot as the pressure of the soles exerted on the force plate and Ω denotes the area of contact between the feet and the force platform. Fa and Fb are forces which represent the support forces at the edges of the force plate. The measurements μ are force differences given by:

$\mu = \gamma(Fa - Fb)$

γ is a gain factor due to the strain gauges and electronics.

Force Equilibrium:

One the body:
$$\iint_\Omega F_{foot}(x, y)dxdy = mg$$

On the force plale:

$$\iint_\Omega F_{foot}(x, y)dxdy = F_a + F_b$$

Torque Equilibria

The force plate equilibrium is:

$$\iint_\Omega F_{foot}(x, y)xdxdy = T_y = T_{bal}$$

$$\iint_{\Omega} F_{foot}(x, y) y \, dx \, dy = T_x$$

The forces Fa and Fb act on the distances a and b from the origin, with resulting torque:

-Faa +Fbb + Tbal = 0

The ankle torque equilibrium results in body sway given by:

$$J \frac{d^2}{dt^2} \theta(t) = mgl \sin \theta(t) + T_{bal}(t), \; J = ml^2$$

Matlab Code for System Identification

Code for extracting data from PostCon and creating a file of input-output data:

```
load filename.dat –ascii
size(filename)
sagittal = transfer(filename,4,1,size)
lateral = transfer(filename,5,1,size)
y1 = sagittal(:,1)
u = sagittal(:,2)
y2 = lateral(:,1)
ipop = [y1,y2,u]
save ipop y1 y2 u
```

Code for creating a reduced order model of an ARX model created using the Identification toolbox:

```
[A,B,C,D] = th2ss(arx)
[Ab,Bb,Cb,M,T] = dbalreal(A,B,C)
[Ab,Bb,Cb,Db] = dmodred(Ab,Bb,Cb,D,: "Size to be reduced")
[Num Den] = ss2tf(Ab,Bb,Cb,Db)
Sysd = tf(Num,Den,1)
Sysc = d2c(Sysd)
```

```
***** Create the N4SID
Z1 = [y1 u]
Z2 = [y2 u]
TH1 = n4sid(Z1, 1:10)
TH2 = n4sid(Z2, 1:10)
```

World Up Program Code

The following sections contain the pertinent code required to run the Rotating Cylinder Virtual Environment:

Start up Script

```
global TextBox1 as string
global TextBox2 as string

sub GetParameters(DisplayType as integer, Borders as integer)


Begin Dialog GetParametersDialog ,,169,268,"Posturography Virtual
Environment"
      OKButton 60,252,44,14
      OptionGroup .DisplayType
            OptionButton 15,96,56,8,"Monoscopic",.OptionButton1
            OptionButton 16,108,56,8,"Active Stereo",.OptionButton2
            OptionButton 16,120,64,8,"Passive Stereo",.OptionButton3
      GroupBox 8,84,80,52,"Display Type",.GroupBox1
      GroupBox 92,84,72,52,"Window Type",.GroupBox
      OptionGroup .Borders
            OptionButton 96,96,56,8,"With Border",.OptionButton4
            OptionButton 96,108,64,8,"Without Border",.OptionButton5
      Text 4,8,164,36,"Virtual Environment Design for Posturographic
Tests carried out by Öron- Näs- Halsklinik, Lunds Universitetets
Sjukhuset, Lund, Sweden"
      Text 4,48,156,16,"Press ""Q"" to quit simulation, and ""0"" to
reset view",.Text2
      Text 4,68,143,8,"Please choose the Display
Characteristics:",.Text4
      GroupBox 8,140,160,44,"Group Box",.GroupBox2
      TextBox 40,152,108,12,.Name
      TextBox 68,168,80,12,.Personnummer
      Text 16,152,20,8,"Name",.Text5
      Text 16,168,48,8,"Personnummer",.Text6
      GroupBox 8,188,160,60,"Test Number",.GroupBox3
      OptionGroup .Testnumber
            OptionButton 20,200,64,8,"Constant Speed",.Constspeed
            OptionButton 20,212,64,8,"Step",.Step
            OptionButton 20,224,64,8,"Multistep",.Multistep
            OptionButton 20,236,64,8,"Ramp",.Ramp
            OptionButton 92,200,56,8,"MultiRamp",.MultiRamp
            OptionButton 92,212,56,8,"Sinusoidal",.OptionButton11
            OptionButton 92,224,56,8,"Random",.OptionButton12
            OptionButton 92,236,72,8,"Quiescent
Stance",.OptionButton13
End Dialog

      Dim TheParameters As GetParametersDialog

      TheParameters.DisplayType = 0
      TheParameters.Borders = 1
      TheParameters.Name = ""
      TheParameters.Personnummer = ""
```

```
        Dialog TheParameters


        DisplayType = TheParameters.DisplayType
        Borders = TheParameters.Borders
        TextBox1 = TheParameters.Name
        TextBox2 = TheParameters.Personnummer


end sub


sub main

dim TheWindow as new Window
dim DisplayType as integer
dim Borders as integer
dim ThreeDDrawTask as Script
dim DrawTask as Script
dim success as integer
dim TheViewPoint as viewpoint
dim TheColor as RGB

        '** Reset The Viewpoint to the start position
        set TheViewPoint = getViewPoint("Viewpoint-1")

        GetParameters DisplayType, Borders ', Testnumber

        '** Get and set the Window and Viewport

        select case DisplayType
        case 0
                TheWindow.DualChannelStereo = false
                TheWindow.Stereo = false
        case 1
                TheWindow.DualChannelStereo = false
                TheWindow.Stereo = true
        case 2
                TheWindow.DualChannelStereo = true
                TheWindow.Stereo = false
        end select


        TheColor.red = 0
        TheColor.green = 0
        TheColor.blue = 0

        TheWindow.Borderless = (Borders = 1)
        TheWindow.LeftEdge = 0
        TheWindowTopEdge = 0
        TheWindow.Width = Screen.Width
        TheWindow.Height = Screen.Height

        TheWindow.setBackgroundColor TheColor

        set DrawTask = getScript("HeadsUpScript")
        set TheWindow.DrawTask = DrawTask
        set TheWindow.DrawTask3D = ThreeDDrawTask

        set TheWindow.Viewpoint = TheViewPoint
```

```
        success = TheWindow.construct("MainWindow")
        set Foundry_Window = GetWindow("MainWindow")

        set Foundry_Viewport = GetViewport("MainWindow-Viewport")
        set Foundry_Viewport2 = GetViewport("MainWindow-Viewport2")

end sub
```

Script to control the motion of the Cylinder

```
'*** Code run every frame to read the key board and update the
rotation
'*** and translation values

global RotSpeed1 as Vect3D
global Rampfunc as script
global Ramp2func as script
global Ramp3func as script
global Ramp4func as script
global Ramp5func as script
global Ramp6func as script
global Ramp7func as script
global Ramp8func as script
global Ramp9func as script
global Ramp10func as script
global Ramp11func as script
global Ramp12func as script

sub task( obj as Moving )

        '*** Define and Initialise Variables
        dim keypress as string
        dim ObjPosition as Vect3D
        dim ZeroVector as Vect3D
        dim TheParent as Group
        dim Position2 as Vect3D
        dim vp as ViewPoint


        set vp = getViewPoint ("Viewpoint-1")

        obj.getRotationSpeed RotSpeed1

        Vect3DInit ZeroVector
        Position2.x = 0
        Position2.y = 0
        Position2.z = -100


        set Rampfunc = GetScript("RampScript")
        set Ramp2func = GetScript("Ramp2Script")
        set Ramp3func = GetScript("Ramp3Script")
        set Ramp4func = GetScript("Ramp4Script")
        set Ramp5func = GetScript("Ramp5Script")
        set Ramp6func = GetScript("Ramp6Script")
        set Ramp7func = GetScript("Ramp7Script")
        set Ramp8func = GetScript("Ramp8Script")
        set Ramp9func = GetScript("Ramp9Script")
        set Ramp10func = GetScript("Ramp10Script")
```

```
set Ramp11func = GetScript("Ramp11Script")
set Ramp12func = GetScript("Ramp12Script")
'set sinfunc = GetScript("SinfuncScript")

'*** Read the Keyboard
keypress = GetKey()

if keypress = "s" then
      obj.AddTask Ramp3func
end if

if keypress = "x" then
      obj.AddTask Ramp4func
end if

if keypress = "a" then
      obj.AddTask Rampfunc 'Ramp up 10
end if

if keypress = "z" then
      obj.AddTask Ramp2func 'Ramp down 10
end if

if keypress = "d" then
      obj.AddTask Ramp5func 'Ramp up 30
end if

if keypress = "c" then
      obj.AddTask Ramp6func 'Ramp down 30
end if

if keypress = "f" then
      obj.AddTask Ramp7func 'Ramp up 40
end if

if keypress = "v" then
      obj.AddTask Ramp8func 'Ramp down 40
end if

if keypress = "g" then
      obj.AddTask Ramp9func 'Ramp up 50
end if

if keypress = "b" then
      obj.AddTask Ramp10func 'Ramp down
end if

if keypress = "h" then
      obj.AddTask Ramp11func 'Ramp down
end if

if keypress = "n" then
      obj.AddTask Ramp12func 'Ramp down
end if


if keypress = "1" then RotSpeed1.x = 10
if keypress = "2" then RotSpeed1.x = 20
if keypress = "3" then RotSpeed1.x = 30
if keypress = "4" then RotSpeed1.x = 40
if keypress = "5" then RotSpeed1.x = 50
```

```
        if keypress = "6" then RotSpeed1.x = 60
        if keypress = "7" then RotSpeed1.x = 70
        if keypress = "8" then RotSpeed1.x = 80
        if keypress = "9" then RotSpeed1.x = 90
        if keypress = "q" then RotSpeed1.x = -10
        if keypress = "w" then RotSpeed1.x = -20
        if keypress = "e" then RotSpeed1.x = -30
        if keypress = "r" then RotSpeed1.x = -40
        if keypress = "t" then RotSpeed1.x = -50
        if keypress = "y" then RotSpeed1.x = -60
        if keypress = "u" then RotSpeed1.x = -70
        if keypress = "i" then RotSpeed1.x = -80
        if keypress = "o" then RotSpeed1.x = -90

        '*** Do things depending on which key pressed
        if keypress = "Q" then
             RotSpeed1.x = 0
             vp.SetPosition ZeroVector
             simulationstop
             obj.RemoveTask Rampfunc
             obj.RemoveTask Ramp2func
             obj.RemoveTask Ramp3func
             obj.RemoveTask Ramp4func
             obj.RemoveTask Ramp5func
             obj.RemoveTask Ramp6func
             obj.RemoveTask Ramp7func
             obj.RemoveTask Ramp8func
             obj.RemoveTask Ramp9func
             obj.RemoveTask Ramp10func
        end if

        if keypress = "up" then
             RotSpeed1.x = RotSpeed1.x - 1
        elseif keypress = "down" then
             RotSpeed1.x = RotSpeed1.x + 1
        elseif keypress = "left" then
             obj.rollparent -1
             obj.yawparent -1
             RotSpeed1.y = RotSpeed1.y - 1
        elseif keypress = "right" then
             obj.rollparent 1
             obj.yawparent +1
             RotSpeed1.y = RotSpeed1.y + 1
        elseif keypress = "0" then
             RotSpeed1.x = 0
             vp.SetPosition ZeroVector
        elseif keypress = "p" then
             vp.SetPosition Position2
        end if

        set obj.RotationSpeed = RotSpeed1

        '*** Rotate the Cylinder
        obj.TimeRotate RotSpeed1.x, 0,0, LocalFrame

    end sub
```

Script to write the translation and rotation data of the Rotating Cylinder

```
global TextBox1 as string
global TextBox2 as string
global RotSpeed1 as Vect3D

declare function timeGetTime Lib "winmm.dll" as long

global Milliseconds as long

sub task (obj as Moving)

dim filenumber as integer
dim ThePosition as Vect3D
dim TheRotation as Orientation

Filenumber = freefile

open "c:\Documents and settings\shovi\" & TextBox1 & TextBox2 &
"Cylinder.txt" for append as #filenumber

Milliseconds = timeGetTime
obj.GetGlobalLocation ThePosition, TheRotation
obj.getRotationSpeed RotSpeed1

print #filenumber, Milliseconds & " ";
print #filenumber, format$(ThePosition.x, "Fixed") & " " &
format$(ThePosition.y, "Fixed") & " " & format$(ThePosition.z,
"Fixed") & " ";
print #filenumber, format$(TheRotation.x, "Fixed") & " " &
format$(TheRotation.y, "Fixed") & " " & format$(TheRotation.z,
"Fixed") & " " & format$(TheRotation.w, "Fixed") & " ";
print #filenumber, format$(RotSpeed1.x, "Fixed") '& " " &
format$(FrameDuration, "General Number")

close #filenumber

End sub
```

Script to write the translation and rotation data of the "Flock of Birds" Device

```
global TextBox1 as string
global TextBox2 as string

declare function timeGetTime Lib "winmm.dll" as long

sub task (obj as ViewPoint)

dim filenumber as integer
dim Translation as Vect3D
dim Rotation as Orientation
dim Milliseconds as long

Filenumber = freefile
```

```
open "c:\Documents and settings\shovi\" & TextBox1 & TextBox2 &
"Viewpoint.txt" for append as #filenumber
'*******
Milliseconds = timeGetTime
obj.GetOrientation Rotation
obj.GetPosition Translation


print #filenumber, Milliseconds & " ";
print #filenumber, format$(Translation.x, "Fixed") & " " &
format$(Translation.y, "Fixed") & " " & format$(Translation.z,
"Fixed") & " ";
print #filenumber, format$(Rotation.x, "Fixed") & " " &
format$(Rotation.y, "Fixed") & " " & format$(Rotation.z, "Fixed") & "
" & format$(Rotation.w, "Fixed")


close #filenumber

End sub
```

Script to increment the speed from 0 to 20 deg/s in approximately 8 seconds and then bring rotation speed back to 0.

```
'********* Ramp.ebs

global RotSpeed1 as Vect3D
global Rampfunc as script

sub task( obj as Moving )

dim Duration as double
dim acceltime as double
dim increment as double
dim finspeed as double
dim part2 as double
dim limit as double

limit = 20.0

obj.getRotationSpeed RotSpeed1

Duration = 0.012
acceltime = 9
finspeed = 20

part2 = acceltime/Duration
increment =  finspeed/part2

RotSpeed1.x = RotSpeed1.x + increment

set obj.RotationSpeed = RotSpeed1

if RotSpeed1.x > limit then
     RotSpeed1.x = 0
     set obj.RotationSpeed = RotSpeed1
     obj.RemoveTask Rampfunc
end if
```

```
end sub
```

Script to decrement the speed from 0 to -20 deg/s in approximately 8 seconds and then bring rotation speed back to 0.

```
global RotSpeed1 as Vect3D
global Ramp2func as script

sub task( obj as Moving )

dim Duration as double
dim acceltime as double
dim increment as double
dim finspeed as double
dim part2 as double
dim limit as double


limit = -20

obj.getRotationSpeed RotSpeed1

'Duration = FrameDuration
Duration = 0.012
acceltime = 9
finspeed = -20

part2 = acceltime/Duration
increment =  finspeed/part2



RotSpeed1.x = RotSpeed1.x + increment

set obj.RotationSpeed = RotSpeed1

if RotSpeed1.x < limit then
     RotSpeed1.x = 0
     set obj.RotationSpeed = RotSpeed1
     obj.RemoveTask Ramp2func
end if

end sub
```

Script to Play Sound

```
sub task(waterfall as Sound)

waterfall.Playing = true
end sub
```

Key Press List

KeyPress	Speed Action
1	10
2	20
3	30
4	40
5	50
6	60
7	70
8	80
9	90
0	Zero Vector
q	-10
w	-20
e	-30
r	-40
t	-50
y	-60
u	-70
i	-80
o	-90
a	Ramp to 20
s	Ramp to 40
d	Ramp to 60
f	Ramp to 80
g	Ramp to 100
h	Ramp to 120
z	Ramp to -20
x	Ramp to -40
c	Ramp to -60
v	Ramp to -80
b	Ramp to -100
n	Ramp to -120
p	Position 2
↑	Speed+ 1
↓	Speed - 1
←	Pitch + 1, Yaw + 1
→	Pitch + 2, Yaw + 2

Technical Specifications for Flock of Birds Device

Technical Specifications for Cy-Visor DH-4400 VP Head Mounted Display