Immersive Brain Entrainment in Virtual Worlds: Actualizing Meditative States

Dr. Ralph Moseley, School of Science & Technology, Middlesex University, London, UK
r.moseley@mdx.ac.uk

Abstract Virtual Reality with associated hardware and software advances is becoming a viable tool in neuroscience and similar fields. Technology has been harnessed to modify a user's state of mind for some time through different approaches. Combining this background with merged reality systems, it is possible to develop intelligent tools which can manipulate brain states and enhance training mechanisms.

1 Introduction

There has always been a fascination with finding ways of controlling or manipulating the human brain, probably since prehistory. As technology has developed, man has noticed that certain external situations can influence and induce a particular internal state. Possibly the first noticeable effects for our human ancestors were how the flickering of the fire would bring about a restful state, or the movement of light through trees would somehow shift the daydreamer's mind. The study of past history and current primitive cultures also reveals the use of sound, as a tool, adjust or induce trance states during shamanic or ritual. The use of light within the classical philosophical era was explored by both Apuleius (circa 125 C.E) and Ptolemy (circa 200 C.E) using and studying strobe mechanisms which appeared to alter the watcher's state of mind [1][2].

More recently, scientists such as the 17th Century Belgian scientist Plateau, discovered how to use flicker fusion – the ability to discern whether light flashes appear to the watcher as solid unwavering light as a diagnostic tool. In healthy individuals the light would appear to be flickering at higher frequencies. Further to this, more recently still, it has been found that regular long term meditators can discern flickering at much higher frequencies than individuals who do not practice the meditation techniques [3].

Strobe lighting has also been used in this way, therapeutically. Found initially by the French psychologist Pierre Janet at the turn of the 20th Century, observed that patients at the Salpetriere Hospital in Paris became more relaxed and less affected by hysteria when exposed at particular frequencies and durations to the stroboscope [3].

2 Sound Effects

There are three distinct sound modulations which affect the human brain and need to be discussed here.

2.1 Binaural beats

In 1839, Heinrich Wilhelm Dove, found that when tones are played in each ear but separated very slightly in frequency, a single tone is made apparent to the listener depending on the difference between the two [4]. For example, if a 300Hz tone is played in one ear and a 310Hz tone is played in the other through headphones, a "beat" frequency of 10Hz is heard to be present. This tone became known as a binaural beat and is perceived by the listener as occurring totally naturally, as if without hearing the tones playing separately in each ear. For this effect to be present, the individual tones should be below 1000Hz and the separation between the two individual tones played to each ear should be no greater than 30Hz. If a wider band is applied than the tones become distinct and separate.

Binaural beats are formed internally by the neural output from the ears. Created inside the olivary body within the brain, it is an attempt to locate a sound source based on phase.

2.2 Monaural Beat

A monaural beat is present, for example, when two guitar strings are tuned closely but not exactly in frequency, or another example is when a binaural beat is played over loudspeakers rather than headphones and the direct separation is lost. The actual monaural beat is formed by the adding or subtracting of the two waveforms as they interact, effecting their amplitude, becoming louder and quieter in a continuing cycle. In both the binaural and monaural beats the lower tone is known as the carrier and the upper, the offset.

Interestingly, monaural beats are dependent on the amplitude of both sounds to be similar whereas the binaural tone is not, to the extent of one of the tones can be outside the hearing threshold entirely and it will still re-create the beat tone. Yet another aspect is in the use of introducing noise to such signals. In the case of the monaural beat, noise will degrade the sound, whereas in the case of the binaural beat it will become yet more prominent.

Both of these tones are rarely found in nature but are commonplace within the mechanical human world. An example of this is found where motors or engines are running at similar but slightly varying speeds and the vibrations meet in an area surrounding them.

2.3 Isochronic Tone

An isochronic tone can be defined as evenly spaced beats of a single tone which are repeated in rapid succession. They are sharp tones that quickly rise to full amplitude and fall away to nothing. This effect is again perceived most strongly in headphones.

All these tones can be embedded in music or left as they are for the listener, though this may be unpleasant, particularly in the case of isochronic tones [5].

3 Brain entrainment with sound and light

The use of EEG (Electroencephalography), MRI (magnetic resonance imaging), MEG (magnetoencephalography) and NIRS (near-infrared spectroscopy) scanning devices have allowed the study of the human brain as never before and also in ways which allow for interactivity with the subject. They have allowed the mapping of human brain states which manifest in everyday life as moods or arousal of varying degrees [6].

Entrainment is an effect that has been noted whereby the human brain's prominent electrical wave frequency can be induced to "track" an external signal when the stimulus lays in the range of brainwave frequency. This frequency following response makes the brain move toward the stimulus frequency, alters the dominant waveform and therefore the overall state of the subject. Various effects are known to occur as part of the entrainment process, such as the excitement of the thalamus when exposed to the various beat tones. Other attributes of brain functionality seem to be affected by this, including spatial perception, stereo auditory recognition and also the activation of many sites in the brain.

For example, isochronic tones are widely regarded as one of the best tone-based methods for brain entrainment and elicit a strong cortical response [7]. An individual that does not respond particularly well to binaural tones often does better with the isochronic type.

The entrainment stimulus can be therefore light, sound, or a combination of both, as long as the frequencies used fall in the range that are present in the brain.

3.1 Other Methods

Besides light and sound and combinations of both there does exist other techniques for altering a subject's brain state, verifiable by scanning devices. Light and sound could be seen as objects in themselves in the meditation process. Other techniques involved silencing and witnessing (mindfulness). Another actual technique can be guided visualizations or a guided talk which directs the consciousness toward particular points in the body or even external to the body. Visualizations may involve focusing on a point or seeing something at that point such as a light. This may or may not synchronize with the breath.

A good example of spoken techniques and their usage is Headspace.com which offers guided voice for several areas toward a particular goal, for example help with:

- Stress and Anxiety
- Focus
- Relationships
- Sleep
- Self esteem

Meditation, its techniques and states will be looked at in more detail.

4 Identified Brain States

Electronic scanning equipment has led to the mapping of the brain and its associated states for given activities and modes. EEG is usually non-invasive though in specific applications can be internally sited. EEG reading normally records the electrical activity along the scalp. These voltage fluctuations result from ionic current in the neurons of the brain. A recording measures the electrical activity over a given period of time via multiple electrodes placed over the surface of the scalp. Analysis and diagnosis relies on studying the spectral content of the output. Typically EEG will be used to diagnose epilepsy which causes abnormal readings but also can be used to find cases of sleep disorders, brain death, coma, encephalopathies. It can also be used as an initial diagnosis of tumours, focal brain disorders and stroke, although, this has become much less with development of other high resolution scanning methods such as MRI and CT. EEG can be limited in terms of spatial resolution and other methods are better at this aspect. However, for temporal analysis EEG can provide better data than methods that rely on heavier processing (and therefore slower).

An EEG can take electrode data from multiple points on the scalp to provide a good map of brain activity. Along with this data, sometimes other non-useful cerebral information is collected too, known as artifacts. An example of this may be the electrical activity associated with blinking and eye movements or other such ocular muscle activity. Other artifacts are also sometimes present such as cardiac, muscle activation and tongue related (glossokinetic). There are various algorithms which can attempt to clean these from the collected data.

Using the EEG (and with certain other scanning devices) it is possible to discern the most dominant waveform state in the brain (though of course other waveforms are present at different spatial locations). The useful cerebral signal falls between 1 – 20 Hz (though gamma can reach a lot higher) and divided up into waveform bands which signify particular overall brain states. These bandwidths are known as alpha, beta, theta, delta and gamma though may be further divided up if necessary into higher and lower versions of these components, if required.

At the lower end of the spectrum, with usually <4 Hz, are delta waves. These usually have high amplitude and show deep sleep in adults but are also present in babies. They can be related to particular pathologies such as lesions and hydrocephalus. These waveforms have been seen in some tasks involving continuous attention.

Theta waveforms appear at 4-7Hz. These appear in young children and when adults and teens are drowsy or idling. Interestingly, they also appear when a person is trying to actively repress a response or action. The pathology that appears is similar to the delta waveform.

As the frequency increases, alpha type waves appear between 8-15Hz. These relate to relaxed states where the person may be reflecting, for example. They are also more likely to appear with closed eyes. The amplitude of this waveform is seen to increase on the dominant side. Pathology can generally be consistent with a coma.

Mu waves, which show between 8-13Hz, overlap with other bands. This band shows the synchronous firing of motor neurons in the rest state.

Between 16-31Hz is the beta bandwidth which can show a range of mental activity from active calm to quite a busy state internally. However, the beta state is usually representative of active thinking, focus, highly alert or even anxious. These waveforms tend to be evenly spread, spatially but with a low amplitude waveform. The pathology here can relate to anxiety.

The gamma band is >32Hz and shows when cross-modal activity is taking place, such as the processing of multiple sense information. It also takes place where short term memory matching is occurring of sounds, objects or tactile sensations. A decrease in gamma band activity, when combined with a similar diminution in the theta, can relate to general cognitive decline.

4.1 Targeting meditation states

The project here focuses on the induction into what could be characterized as meditative states.

Meditation in the Eastern context is seen as a tool for spiritual development where the aim is to reach transcendental states and/or the cultivation of inner peace, focus and positive emotions. This is also seen as a way to reduce stress, agitation and negative emotions. A Western model of meditation describes a self-regulatory exercise which is used to focus the attention and through this reach a deeply restful but fully alert state. These definitions, together, actually form a mid-ground describing a model which encompasses a definition of meditation that focuses on maintaining the attention and awareness with a goal to create a better sense of well-being and serenity.

4.1.1 Positive effects

Meditation has been studied for some time and in-depth due to its proponents' claims that it has positive effects on the human condition, general well-being and spiritual aspirations. This has been largely backed up by clinical trials and studies. There are many cases where symptoms have been improved in various disorders such as depression and anxiety [8]. Other successful areas effected include eating disorders, addictions and disorders caused by psychoactive drugs [9], stress and anxiety disorders, blood pressure and cholesterol level normalization [10]; lowering the intensity of emotional arousal [11]; enhancement of positive affect and resilience to negative affect [12]; executive functions enhancement such as attention; working memory; verbal fluency; cognitive flexibility; introspection; and better perceptual discrimination; increase compassionate behavior; improved immune function; enhanced functional and structural neuroplasticity [13] and longer life spans.

Unfortunately, there are a lot of empirical studies where there is a lack of sound methodologies applied – many stretching back to the 1970s. Some indicate biases and a lack of good control groups used. These biases, for example, may lean toward a particular technique or emphasis. Participants may self-elect to take part in a trial (such as experienced meditators) with only demographical matched controls, making the conclusions difficult to draw. Other problems have included overlapping of samples of meditation practitioners.

Despite these flaws in the methodology of some studies, there is still a large amount of evidence to suggest meditations positive effects and because of this, it is a widely used exercise which acts on the mind and body. However, to report only this is largely a one-sided view and there are studies which reveal contra-indications and negative effects to its practice.

4.1.2 Negative effects

There are a number of both short term and long term negative effects that have been found related to meditation practice. These include, panic attacks and anxiety [14]; depersonalization syndrome [15]; high blood pressure; over-excitation of the nervous system; brain epileptization [16]. A study of twenty-seven long-term meditators [17] found 62.9% of the group reported at least one adverse effect while 7.4% suffered more profound negative effects. In these cases the adverse effects included relaxation-induced anxiety and panic, increases in tension, less motivation in life, depression, increased negativity, boredom, pain, impaired reality testing, confusion and disorientation, feelings of being in a "spaced out" state.

Some meditation practices include alterations in breathing and hyperventilation. These have been found to reduce cerebral blood flow by 50%, due to central neurogenic response to hypocapnia meditated by the brain stem [18]. This leads to several negative effects in itself: ischemia; association with inducing seizures [19]; increase in cortisol and human growth hormone, which relate to depression and decreased attention and cognitive function.

Studies have also shown the occurrence of acute psychotic illness appearing in some beginner practitioners [20]. Intense practices within Yoga and meditation have given rise to the emergence of a set of symptoms labelled "Physio-Kundalini Syndrome". An individual may experience significant disruption due to the appearance of unusual phenomena labelled by some as "spiritual emergency" but could precipitate forms of mental disorders or bring forward underlying psychiatric conditions. This is recognized in the Manual of Mental Disorders (DSM) as "Qi-gong Psychotic Reaction" and is described as "an acute, time limited episode characterized by dissociative, paranoid or other non-psychotic symptoms … Especially vulnerable are individuals who become involved in practice" [21].

Many aspects of an individual, such as their introversion versus extroversion and anxiety levels change the possible outcome of meditational practices [22] and therefore may change any positive effects into negative. It is possible, for example, that an individual suffering from depression or past trauma, who is hoping to find some relief in meditation practices, or training, may actually find they become more anxious rather than less, no matter how much they follow the instructions to concentrate on the present moment.

Positive effects of meditation can also become negative if an individual has particular constitutional neurophysiological characteristics. An example of this is the ability of long term meditators to develop high pain tolerance and circumstances where the normal reaction would be adverse, such as painful stimuli to be tolerated.

This feature which is indirectly trained through the course of the meditation practice [23] could actually be undesirable in particular circumstances where a person may be instinctually motivated to pull away. This insensitivity may cause injuries or further damage to an area where it could be prevented, if felt properly. Other trained aspects in long term meditators include introspection, observing thoughts and rising emotions, as well as other objects in the world in a detached, dispassionate manner. If overexpressed in predisposed individual, this could lead to problems, leading to a psychotic world-view similar to those found in schizophrenics. This kind of psychosis is characterized by a fundamental disintegration in conscious experience and fragmentation of the self, with the inability to integrate perceptual information and thoughts [24].

The orbitofrontal cortex (OFC) is quite often enhanced in long term meditators [25]. The OFC plays a part in emotional regulation, particularly down-regulating and re-appraising negative emotional states. If overexpressed it could lead to types of mania or borderline personality disorder, leading in turn to an inability to feel empathy or compassion.

The hippocampus in meditators has been shown to have enhanced activity or larger volume [26]. This enhancement may lead to the reactivation of memories or exaggerated self-esteem. In particular individuals with particular neuropsychological characteristics could lead to serious problems involving obsessive and intrusive thoughts, dissociation and flashbacks, all relating to this type of enhancement in the hippocampus.

The default mode network (DMN) is the part of the brain that remains active when we let the attention wander. This “inattention” and the DMN’s subsequent activation will come about when not attending to physical activity or engaging with the external environment, or carrying on a conversation. The DMN is active in states of daydreaming, contemplating the future, reliving the past or general mental rumination. A well balanced DMN will help the individual plan tasks, review past actions to improve future behavior and remember life detail appropriate for the individual. Some studies have revealed that long-term meditators have reduced the activity and diminished functional connectivity within the default mode network regions of the brain [27]. It is known that the DMN is linked to a sense of self and therefore this could be seen in meditators that there would be a weakening of this function. This may actually benefit some in particular traditions as the self is seen as something which should be lost but there is a risk of depersonalization and loss of personality in some where there is a neuropsychological predisposition.

It is noticeable that a lot of the negative effects show properties of the view of certain meditational practices taken to extreme – for example the diminishing of the self and the muting or dampening of particular functionality in the DMN. These seem to show how the meditation is targeting specific areas in line with the view of the technique and as we shall see in later sections of this work the main basis of meditation techniques which are in common with each other.

It is important to balance the various arguments and current studies in this area. There are large number of studies which indicate positive aspects to meditation, especially in the long-term. Though in some individuals with specific neuropsychological types there may be undesirable effects.

4.1.3 Meditation practices and associated states

A practice which involves the deliberate altering of the mental state with its own technology is meditation. This practice attempts to self-regulate the body and mind, affecting mental activity by utilizing specific attention mechanisms and techniques. The techniques themselves are similar to those used to induce relaxation or altered states such as trance, progressive relaxation or hypnosis. The main technique involved is the regulation of attention which is common to many methods though most meditative styles can be classified into two types, mindfulness and concentrative, depending on how this attention is focused. Mindfulness cultivates a watchfulness, or witness and usually has no object of focus and concentrative will use an object of some kind. Most meditative techniques, or styles, lie somewhere between these two.

Mindfulness will allow thoughts, sensations or feelings to arise without attaching to them or forming a judgmental response or analysis. The field of attention is kept regardless of any incursions by phenomena. Many styles lie in this area such as Vipassana, Zen and Western adaptations of mindfulness practices. Mindfulness encourages an open perceptivity and a meta-awareness of mental content.

Concentrative practices focus on some specific object, mental or sensory activity. This could be a repeated sound, a visualization or body sensation, such as the rising and falling of the breath. The Buddhist Samatha techniques, for example, use the breath as a focus. Transcendental Meditation lies in the concentration style but has some attributes belonging to mindfulness. It has the repetition of a mantra but places emphasis on lack of concentration and the development of witnessing thought-free awareness. The sound of the mantra eventually is supposed to occupy the awareness without the need for concentration to be applied. TM is therefore an example of a technique which crosses over between the two types though the goal is largely the same. Concentrative

techniques do have aspects of mindfulness in that any mental phenomena that do arise are let dissipate and the object returned to, thus entering a witness state similar to mindfulness.

An example of the concentrative practices is known as Kasiṇa (Pali; Sanskrit: kṛtsna), where a disk of a particular colour, dimensions and composition is focused on relating to a particular element or aspect. For example, the earth disk is a red-brown color formed by spreading earth or clay (or another medium producing similar colour and texture) on a screen of canvas or another backing material. These disks are concentrated on until a strong image is created in the mind. Later in the Kasina practice, only mental objects are used, taking the place of the physical disk. The idea of Kasina practice is to settle the mind and form a strong basis for training in meditation.

Practitioners of meditation have been shown to develop particular traits. These tend to vary over the length of practice. A deep sense of calm is realizable, there is a cessation of internal dialogue and development of the ability to merge the awareness with the object of meditation. One of the common experience of meditators is the shift in relationship between thoughts and feelings – there is a metacognitive distance created between arising mental phenomena and the occupying of the full attention. Long term meditators experience a deepening of the main characteristic traits: a deepened sense of calmness, heightened awareness of the sensory field and a greater depending of the shift between thoughts, feelings and alterations to the sense of self. The transcendental state of witness/observer is maintained for longer and the separation between observed and observer is perceived as growing fainter.

Various studies have been carried out to analyze the exact response by the body to particular types of meditation. The results have varied from the initial theory of relaxation response through to arousal and then more recently back to relaxation but this varies depending on the form of meditation utilized.

These techniques, above, fall into the categories defined by Lutz [28], that is, focused attention (FA), which keeps attention focused on an object and open monitoring (OM) which keeps attention involved in the monitoring process itself.

Frequency range	**Name**	**Related attributes and states:**
> 40 Hz	Gamma waves	Higher mental activity, perception, problem solving, fear, and consciousness. Appears in specific meditative states, relating to Buddhist compassion meditations in the Tibetan tradition.
13–39 Hz	Beta waves	The most usual state for normal everyday consciousness. Active, busy or even anxious thinking. Also appears in active concentration, arousal, cognition, and or paranoia.
7–13 Hz	Alpha waves	Relaxed wakefulness, pre-sleep and pre-wake drowsiness, REM sleep, dreams and creative thought or free association. Considered as the brainwaves of meditation. These waves also appear in the relaxation process before sleep.
8–12 Hz	Mu waves	Sensorimotor rhythm, Mu Rhythm.
4–7 Hz	Theta waves	Appears in deep meditation /relaxation, NREM sleep. Also, in hypnotic states or where some element of consciousness. A theta prominent individual may be awake but lose their sense of bodily location, for example.
< 4 Hz	Delta waves	Deep dreamless sleep with loss of body awareness. Does appear in the EEG of very experienced practitioners of meditation and would appear to relate to some ecstatic states. Maintaining consciousness while delta present is difficult.

Table 1. Identifying predominant states and mental content

4.2 EEG and Meditation techniques

As this project and its biofeedback technique are linked to the signature of the EEG and its programmed response within a virtual world, it is wise to look at how these appear within various techniques. Note that it is possible to break down EEG readings into separate areas: the power of the waveform (amplitude), the frequency and the coherence. EEG coherence here can be defined as the wave train becoming more rhythmic and orderly –

it falls into phase and moves synchronously over large areas in the frontal regions of the brain, extending eventually toward the posterior regions. Table 1 gives a summary of states identified in normal life and below, more detail of relevant meditative states are outlined.

4.2.1 Alpha - Theta

The appearance of alpha waveforms has been seen in various types of meditation. Zazen, or Zen meditation is a kind of technique used in Zen Buddhism. A study [29] had 48 priests and disciples of Zen sects of Buddhism as subjects and their EEGs were continuously recorded before, during and after the practice itself. The results showed various stages in the technique very distinctly. In stage I, the beginning, within 50 seconds alpha waves appeared, notably this is whether the eyes were open or not. In stage II their amplitudes increased steadily. As the meditation technique increased over time the alpha wave train would dissipate, for stage III. Finally, at stage IV there was an appearance of a theta wave train.

These stages were identified and evaluated within the disciples' technique by a Zen master.

Yet another study [30], looked at various types of meditation – Yogic, Transcendental and Zazen. EEG was recorded in 30 normal healthy individuals practicing meditation, compared to 10 normal healthy controls not practicing. Here, alpha wave activity was prominent in meditators as compared to the controls. Meditators were said to produce strong alpha waves higher in persons performing meditation with good coherence which suggested "good homogeneity, uniformity and increased orderliness of the brain". There were 15 males practicing TM and 15 males practicing yogic meditation with 10 cases of similar age and sex who were not meditating. All meditators had been in their practice for at least 3 months. EEGs were taken before, during and after the meditation session. In the control group, EEG was taken before and during eyes closed relaxation and after relaxation. EEG was analyzed for alpha frequency, alpha voltage, alpha percentage, alpha coherence and hemisphere symmetry in both control and meditative subjects.

The study revealed no theta waves were evident in any group. Meditators showed persistence of alpha waves after eyes were opened in 28.9% of cases, as compared to 12.4% in control cases. In meditators good coherence was recorded during meditation. The interhemispheric time difference in alpha frequency was 12.79 +/- 8.34 milliseconds, which becomes 8.75 +/- 5.65, indicating good coherence. A good hemispherical symmetry was suggested by the right and left voltage ratio, which was 0.844 before meditation and 0.876 during meditation. Cardio-respiratory readings showed that the pulse and heart rate slowed down significantly in meditator groups. Respiratory rate also become less in the group practicing meditation techniques. Blood pressure was seen to show a fall of the systolic blood pressure only, where the diastolic blood pressure remained the same. ECG did not show any abnormal signals being recorded. The alpha waves recorded here were suggestive of an increased relaxed state of mind. The alpha voltage is inversely related to mental activity; an increase in voltage is accompanied by the decrease in the frequency which occurs due to lessening in brain activity. This could be due to decreased energy metabolism of the brain [31].

An EEG pattern which characterizes that of sleep was not seen in this study. The sleep EEG is evident when there is a high voltage, slow wave pattern 12-14 Hz, sleep spindles and low voltage mixed frequency, along with rapid eye movements were not seen during the meditation. Alpha waves became present and dominating over 5 to 10 minutes of meditation. Alpha wave activity seemed to dominate where there is activation of diaphragmatic breathing, rather than thoracic breathing. A significant number of meditation techniques use breath mechanisms or breath observation as their object of awareness.

Meditation would seem to lead to the development of right hemisphere abilities [32]. Several researchers found that EEG and theta wave coherence is prominent in the right hemisphere during meditation.

The persistence of alpha waves after eye opening is an aspect which is found in the studies mentioned here and elsewhere. This follows the experience that meditators find the calm and alert state of mind continues after the actual practice.

It is interesting to note that in studies a recurring observation of results seems to take place that in deep meditation states coherence in both hemispheres of the brain appears. These two hemispheres largely split their functionality for example, speech, logical thinking, analytical thought and sense of time are thought to be resident, in the main part, in the left hemisphere. The right hemisphere is oriented toward the ability to recognize faces, comprehend maps and intuitive thinking. The right side is also focused on motor skills and spatial awareness. Meditation also seems to lead to the development of right hemisphere abilities as well as this overall synchronizing of waveforms. Some researchers [33] have found that the synchronization of both frequency and amplitude in electrical activity in all areas of the brain, this has been called "Hypersynchrony", which has been postulated as having some connection with the feeling of pure awareness or consciousness.

Alpha-theta waves have also been shown to present in Kriya yoga with some interesting research findings [34]. Following this particular meditation type, in this study, a significant rise in alpha and theta rhythms was shown in

ten out of eleven subjects. Alpha waves were seen to double in certain individuals. Kriya yoga consists of a number of levels of pranayama (breathing techniques), mantra (repetition of phrases or words) and mudra (gestures).

4.2.2 Beta - Gamma

Gamma waveforms and particular types of meditation techniques in studies have been explored. For example, it appears that particular types of Tibetan meditation give rise to gamma wave trains occurring. One 2004 study [35] took eight long term meditators and placed electrodes over the head, monitoring the patterns of electrical activity as they meditated. These results were then compared by researchers to novice meditators who had been given some training and asked to meditate for an hour a day for a week preparation to the experiment itself. In a normal meditative state the two groups performed similarly, that is, the electrical activity produced and rendered by EEG was similar. However, when techniques were introduced that focused on objective compassion by the Tibetan monks the brain activity altered to show a rhythmic coherence, suggesting the neuronal structures in the brain were firing in a synchronized manner. This activity was occurring in the gamma band between 25-40Hz. Apart from those seen in seizures, these gamma wave oscillations were the largest seen in humans. The novice meditators showed very little gamma wave production though with further experience and training the rhythmic signals from them appeared to strengthen, which possibly shows that the gamma band rhythm is trainable in itself. There would seem to be some interesting ideas that show a relationship between the tightly focused and synchronized gamma wave train and the heightened sense of consciousness, bliss and intellectual acuity subsequent to meditation.

However, some neuroscientists have disputed this gamma wave argument on the basis of two paths of reasoning; that there is a possibility of mismeasurement, for example, that the EEG could be an artifact of electromyographic activity to other artifacts such as minute eye movements. Both of these have largely been answered with careful signal separation and the use of magnetoencephalography (MEG). MEG does not have the same problem with discerning between artifacts that are associated with EEG and has identified gamma activity associated with sensory processing, mainly in the visual cortex.

4.2.3 Delta

Delta waves are a high amplitude brain wave between 0-4 Hz. They are usually associated with particular stages of sleep and have been purported to aid in the formation of declarative and explicit memory formation.

A particular type of Yogic meditation know as Yoga Nidra (literally, sleep yoga) leads to a consciousness being present while in delta-sleep. This technique leads the body to actually enter the sleep state; a series of observations are made initially by the practitioner, accustoming them to the locale they are actually in as a means of making the mind placid. A “body scan” then takes place to simply relax. The next stage is making a positive resolve or statement, known as Sankalpa in Sanskrit. A stage is then entered which is called the “rotation of consciousness”. Here there is a directing of the mind to parts of the body in sequence. This sequence is usually spoken out loud via a recording or teacher. The practice continues with awareness of the body and its contact with the floor, awareness of subtle body movements, awareness of opposing sensations, a focusing on “inner space”, visualizations, and movement in time (a review of the events of the day). Finally, there is the repeating of the resolve, stated earlier and a completion section, where awareness is brought back to the body, the room and external surroundings. Various studies have shown how this method leads the practitioner from normal beta activity, through the relaxation stage where alpha predominates. As the body-mind relaxes further but is still occupied in a meditative state, theta appears and finally, the individual may exhibit delta. A particular study showed that after 30 sessions of Yoga Nidra, alpha activity could be made stronger, leading eventually to introduction of theta intermixed with alpha – the signature of a deep state of relaxation.

5 Sound and Light Machines

Sound and light machines (also known as mind machines) use both visual and auditory mechanisms to deepen the overall impact of the immersive experience. This technology was developed from experiments in psychology and consciousness research and what was initially bulky machines eventually became small handheld units in the 1970s onwards. These use synchronized strobing of light and sound at known frequencies causing the frequency following response to occur and "lock on" over periods of time. The frequencies themselves can change over time visiting various states.

A sound and light machine, as available commercially, is composed of goggles or eyeglasses which are opaque, and headphones. The eye piece usually has a set of LED in front of the eyes which are controlled by the core unit, containing the processor and programs. This LED array can be single color or multiple depending on the sophistication of the model but all tend to be able to vary the intensity. More expensive sound and light machines tend to also have brighter output. Multiple colour LEDs give a range of shades and depth. It must be remembered that the eye set is worn with eyes closed and therefore give a diffuse effect on the back of the lids that you are watching. The general effect as the program runs is of mandalas and geometric shapes, spires and cracked landscapes, mesmerizing and surprisingly detailed, considering the eyes are closed.

Commercial units, such as the more basic Procyon [36], are capable of producing programs which target specific states in the progress of one session. This device produces sequences of variable light and sound pulses to specific programs which can be built-in or user-defined. The sound and light characteristics and duration are variable and programmable. It is possible to create washed out fields over the user's field of vision (this is known as a true Ganzfeld effect [37][38], from the German meaning "complete field"), through to shimmering cascades, all with an accompanying audio sound track of pulses.

Similar to other machines, a complete program may have an overall aim such as meditation, learning stimulation or sports focus but the actual program may travel through several frequencies for varying durations to get there.

Kasina (which is actually named after the meditation technique which concentrates on an external object) is a more recent mind machine from Mindplace which has even more expanded capability [39]. This unit incorporates a more sophisticated sound synthesis engine for playing the audio pulse tones as well as the ability to play MP3 data. This allows for the playing of samples or environmental sound tracks which may have embedded frequency encoding.

A technique used by the Kasina, as well as the more rudimentary sound and light frequency pulsing, is that of music modulation. It is possible to modulate any music in such a way that a binaural or monaural frequency following response is initiated. For example, it is possible to modulate only the bass track of a piece of music using low pass filtering to select that particular band and thus avoid distorting other components that lie within the soundscape. A binaural beat could then be integrated within the frequencies present, using modulation techniques. The Kasina contains many such tracks which are musical, for example, shamanic drum patterns and Tibetan bowls, or environmental sounds such as rainforests or seashores.

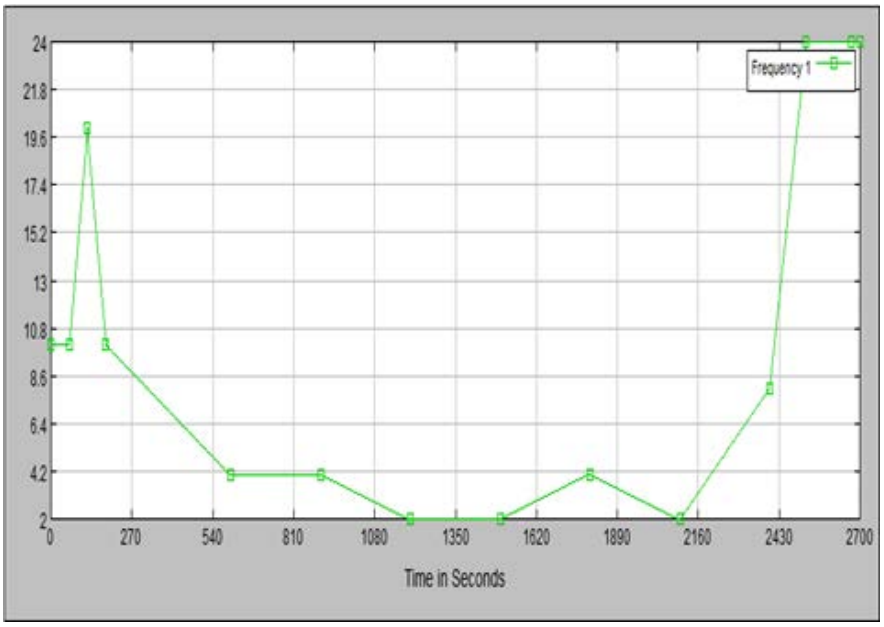

Fig. 1. Showing light frequency for a program in Kasina

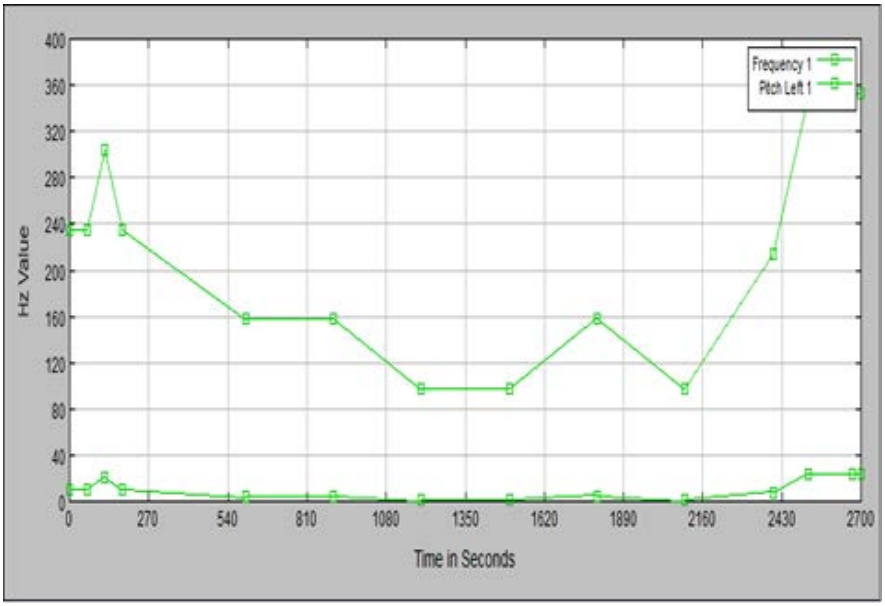

Fig. 2. Showing light frequency in relation to audio for a program in Kasina

Figures 1 and 2 show the output from a program for the Kasina which attempts to induce a “meditative state”, that is, the brainwave “signature” exhibit properties that look like those in an adept meditator. This particular program has an initial burst to stimulate, followed by the waveform dropping in frequency steadily until the lowest point is reached of just 2Hz, which is actually classed as a delta waveform state. The waveform then steadily climbs again. This entire programmed session lasts over a period of 45 minutes.

6 General Description of the project

The general idea for this experimental project is the development of an environment in a 3D virtual world which reacts and adapts to a user's state and then purposely attempts to change the person's state using biofeedback mechanisms to some target EEG waveform.

There are several aspects to this:

- The collection of the EEG information
- The transferring of the data to the Virtual World in an appropriate format
- Process the stream in the Virtual World
- Adapt the virtual environment

This forms the basis of the biofeedback loop which cycles itself. The EEG headset takes the information from the scalp (actually the forehead, in this case), communicates with a program that streams this into the virtual world in a form that will be easy to process within it. This is essential as processing within the virtual world is slower and not necessarily as comprehensive in the programming language available. The virtual environment can then adapt toward the target or, simply reflect the user's state, which is a good first step.

One of the questions at this point may be: What exactly could be used within a virtual world to alter the user's brain state? For this, mind machines and the history of this field, offer plenty of scope for experimentation.

For example the following have been mentioned:

- Stroboscopic based elements
- Ganzfeld lighting effects
- Synchronized audio patterns (monaural, binaural and isochronic beats)
- Embedded audio patterns (the modulation of sound tracks or soundscapes not necessarily obvious to the user)
- Spoken or guided techniques

6.1 NeuroSky EEG

Faster processors and network technology have led to the fast real time capture and processing of brain information, efficiently and without the need for vast arrays of equipment, wiring and external computational power.

NeuroSky produce several types of EEG reader which require no wiring and are connected by fast Bluetooth interface. Mindwave Mobile [40] is a research grade EEG reader based on the TGAM (ThinkGear ASIC Module) bio-sensor chipset featuring Bluetooth interface and software to capture data. Various software is available to record or visualize the data coming from the headset. This unit measures the power output of the various bands such as alpha, beta, gamma etc. and pre-processes particular aspects of interest such as attention, meditation and eye blink. The device is made up of the headset itself, an ear clip and a sensor arm. The ear clip forms the reference and electrical ground and the EEG electrode is on a sensor armature which rests on the FP1 forehead point above the eye. The unit is powered by a single AAA battery, which lasts approximately 8 hours.

The Bluetooth connection allows the EEG to be used with both desktop and mobile devices, such as phones and tablets. This flexibility has encouraged the development of software for both, with desktop software and phone apps available. These range from recording and visualization of brain EEG patterns, to some interesting BCI type control and biofeedback software. For example, one application plays movies and alters the storyline depending on the brainwave output. Another allows the user to attempt to enter a meditative state and responds to their progress by raising a ball on the screen. The height attained equaling the period spent in a characteristic meditative state. Yet another application similarly measures the attention span graphically and originally, by the screen object erupting into flame for the period that the concentration is kept focused. Software is also available on phone apps which will encourage the development of meditation using a diary, logging progress as the user visits day by day.

Other software allows the recording of EEG data into graphical format, rendering it suitable for data analysis. The data itself is collected from the FP1 point – the only electrode available on this commercial device which is somewhat limited but still useful. A good point is that data as mentioned below is to some extent pre-processed (so decomposing with FFT is largely unnecessary) and therefore persistent data which is present at the FP1 site, such as eye artifacts, can be ignored. Raw data is available too, if required.

Although there is a large range of commercial software available for the headset, it was necessary for this project to write a lower level interface to gain access to the raw and semi-processed data directly. The data stream leaves from the headset via Bluetooth and is picked up by the receiving device (in this case the desktop computer) by specific drivers and then processed by the custom software developed for this work. The data available from the headset came in the ranges (and sent as "sets") of low-alpha, high-alpha, low-beta, high-beta, low-gamma, mid-gamma, delta and theta. There are two other uniquely, pre-calculated eSense™ values named, as mentioned previously, meditation and attention or focus [41].

6.2 Virtual Worlds – Second Life and OpenSim

Both Second Life (SL) and OpenSim provide an immersive 3D world where users can create content [42]. Although it is similar to many 3D world games there is no goal, as such, or objectives. The idea being a user enjoys being there, creating content and is active in the virtual world. A viewer similar to a browser allows access to features and interaction with your avatar within this environment. The avatar acts as your character with which other users can be communicated with. This can be initiated through a built in messaging service, which can be localized to the virtual area you are in publically and also in private communications. Such virtual worlds have their own currencies and exchange rates with the outside world.

One of the main aspects of these worlds is the ability to program and create – very useful for prototyping and developing experiments. For example, it is possible to create a virtual vehicle such as a car, designing and building its appearance and then moving on to its actual functionality which is implemented by programming code stored in its constituent parts [43].

The appearance and building of items is vast in scope but has several initial basic components, for example, you can build with prims – a basic building block in various shapes. It is possible to produce gas and fluid too, for various effects. A physics environment is replicated.

The programming language within these virtual worlds is known as Linden Scripting Language (LSL) and is a fully functional programming language somewhat similar to C, Java and the JavaScript family of languages. This contains many library functions for altering and manipulating the virtual environment, controlled by the scope of various ownership permissions. For example, the above mentioned car, if built by myself, would belong to myself and unless altered, its attributes and permissions would only be modifiable by myself.

The library of functions cover all the normal aspects of programming such as string manipulation, security mechanisms, input and output as well more particular functions for the virtual world itself.

Using LSL it is possible to control all aspects of virtual object, it can, for example be made to spin on its axis or change colour or transparency. Objects to create simple sounds using samples. It is also possible to reach outside of the virtual world and link up with servers and computers running other computer code, which can in turn provide or process data. So, it would be possible, for example, to have an object function as a music player with the music stored on an external server, which is streamed in when a play button in the virtual world is pressed.

This aspect of having communication with the external world allows for some interesting developments between the two.

A surface of a prim can also be made into a "media surface" which allows streamed video to be presented, which at its most simple could show a movie or video clip from the outside world. A media surface can also be linked to a website and therefore becoming an extension to YouTube or any other website. This leads to a great deal of versatility when programming the virtual world.

6.3 Advancements in Virtual Worlds

New versions of SL will eventually be available, offering greater resolution and higher frame rates. They will also be calibrated for more immersion using virtual reality headsets.

The first that should be mentioned is High Fidelity, a spin off from SL and by many of the same people, its aims lay in advancements in technology such as sensor feedback and VR. More interestingly is the fact it is open source coding [44].

The second ongoing virtual world is Project Sansar (meaning Universe in Hindi) [45], with yet more involvement with SL, the key goals here are that it works with mobile technology and has advanced expressive

avatars, along with other advancements in virtual technology. The model here would seem to be different in that it is aimed at becoming the Word Press of VR, with commerce using links into the world to provide their own particular virtual areas.

6.4 Virtual Reality, SL and OpenSim

It is possible, using special adaptions to the viewer or a separate viewer built for the purpose, to use SL and OpenSim within virtual reality headsets such as Oculus Rift and Google Cardboard.

Google Cardboard is an affordable and accessible way of putting together a 3D headset. An android or Apple iPhone is used as the viewer is held at some distance from the eyes by a homemade or bought headset. The phone is useful in that it contains all of the technology required: the display, sound reproduction, tilt sensors, accelerometer, camera (if augmented reality is desired) and location sensors. Once the headset structure is acquired or made, apps exist to test the new system as a standalone device. The display provides a stereoscopic view into the 3D environment provided and the various senses detect motion and tilt, thus allowing interaction with the presentation.

To link the system up to an interactive virtual world several steps are required and software. A viewer is used with the ability to interact with a 3D headset, such as CtrlAltStudio. For Google Cardboard a server software is required on the computer to set up communication with the viewer, for example, Trinus VR and on the phone a Trinus VR client app is executed which establishes the link with the desktop. The actual connection link can be via Bluetooth, and therefore wireless, or, by USB tether.

Once the link is established, the information between the desktop and phone flows, providing 3D view to the user, along with sensor information back to the viewer app.

7 Initial Experimentation

A series of stroboscope objects were created for experimentation in SL, these ranged from simple flashing devices to entire rooms (which in itself is an object) where the textures of the prim can be controlled and changed at timed intervals. It was possible to build up complex strobe patterns by using multiple sources. It was also possible to using a media texture and stream in a stroboscope pattern from the outside world.

Similarly, fields or blankets of color which covered the field of vision were made possible along with parallax effects.

Objects were created which could generate audio frequency patterns at particular intervals and played simple synthesized audio, similar to the mind machines, as repeating samples. More complex audio could also be streamed in to receiver objects, similar to the video mentioned above, allowing for longer samples or complex synthesizer programming and modulation.

An audio track could be played from the outside world and modulated to affect the user as desired. This includes spoken word tracks which could be used for guided meditation techniques.

A problem with audio and visual elements may be the ability to synchronize them within an environment which relies on networks, servers and multitasked processing in scripts. It should be possible to have locking mechanisms and keep heavy processing in the outside world where necessary. A good example of where this can be done is where an EEG signal has come from the headset, it can be processed in the outside world and the basic elements abstracted from the data about the current waveform prior to being sent on. This keeps the stream to the minimum and also the processing in-world.

Media objects in-world can be a part of the VECSED merged reality system [46] which will be used for this project (described below) and therefore have easy access to streams and external world devices.

In all likelihood, the adaptive and programmable environment created will have a mix of these elements.

As a starting point the virtual environment which the user is situated in-world can mirror the user's current state and progress toward some pre-defined state. In this case the adaptation takes place where the colors, lights and sound in the "pod" will match this state, initially.

Meditation techniques essentially bring about their goal by two broad techniques, either based on concentration on an object, or through cultivating the witness or mindfulness state. A virtual object can be used as a concentration tool (this is similar to software available) and with this, mind machine techniques can be employed.

7.1 VECSED – Virtual Environment for Control, Simulation and Electronic Deployment

Virtual Reality systems offer excellent capabilities in terms of simulation but usually less so in terms of being able to control, access and communicate with the outside world. This project requires advanced control and communication capabilities to support the various functionalities.

This system acts as a bridge which sits between the real world and the virtual, allowing the coordination of data streams and allowing for simple or complex communication arrangements. A diagram showing the basic arrangement of the system is shown in figure 3.

The VECSED server/database sits between the two worlds, providing a look-up service where resources can be allocated on the basis of requirements. The main core of the VECSED server is written in PHP with a MySQL managed database. Each device (an agent) which registers itself on the system enters various information to the database on the VECSED server such as its network properties, I.P. address, location information and other such details:

- Name of the agent
- IP address and port for communication
- Type of resource
- Hostname, if relevant
- Last time communicated with (Timestamp)
- Geospatial information such as longitude and latitude

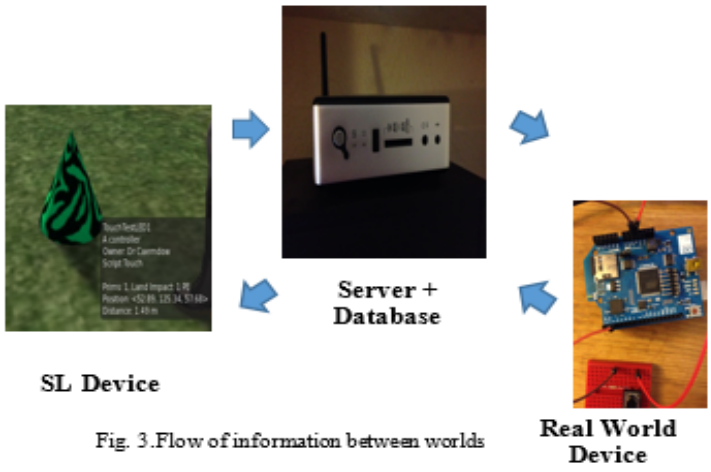

Fig. 3.Flow of information between worlds

Once registered the device must then use secure authentication to initiate communication. When a device boots (or in the case of a virtual device, instantiates) itself, a security procedure authorizes its presence on the merged reality system.

A registered device (such as a virtual constructed object, with programmed functionality) within the virtual world can communicate with VECSED, ask for a particular real world device to link to, or any such type of device. VECSED will then respond and allow a communication link to be set up between the two. In SL any constructed object with its scripts can have an assigned URL for communication (using llRequestURL()), this is passed over to the VECSED server and logged.

A test example was developed in the form of a virtual toggle switch that controls a real world LED light on an Arduino board. Issuing the command:

ArduinoUno LED9 on now

Makes the virtual controller send the activate command via LSL and the HTTP request mechanism (llHTTPRequest()) through to the server page. The information reaches the server as HTTP POST data where it is analyzed. Any incoming commands are security checked that the source is registered first before parsing and then logging state changes etc. with the database. Finally, the information is passed on to the target device.

In this particular example, a TCP/IP socket was opened to the device and the appropriate message built from the parsed command. A C++ program was running on the WIFI equipped Arduino which listened to the port and executed commands that arrive there after looking them up. Here, a LED was activated on the board.

Similarly, a device in the real world can register itself with the VECSED server in exactly the same way, sharing its details such as resources and location. It could then establish a link with a virtual object and send data. An example in this case could be a video camera which is linked to a media device, which in turn could have its control functionality replicated within the virtual world.

7.2 EEG & VECSED Combined

An appropriate driver mechanism was written in Java which linked into the stream coming from the headset. This was necessary as the software available did not allow the degree of manipulation and analysis required for this project. The headset can provide both a raw data stream and a processed stream with strength of the waveforms in particular bands which eliminates the need for fast fourier transform (FFT) analysis. The protocol for the stream packet is detailed in table 2.

The main task of the EEG reader was to interpret the data by parsing the data stream containing PoorSignal, EEG Raw Value, EEG Raw Value Volts, Attention Level, Meditation Level, Blink Strength, Delta (1-3Hz), Theta (4-7Hz), Alpha Low (8-9Hz), Alpha High (10-12Hz), Beta Low (13-17Hz), Beta High (18-30Hz), Gamma Low (31-40Hz), and Gamma Mid (41-50Hz). The data stream itself is composed of packets, an initial code identifying the following information in the row itself.

Code	Byte Length	Data Value Meaning
0x02	1	POOR_SIGNAL Quality 0-255
0x03	1	HEART_RATE (0-255)
0x04	1	ATTENTION eSense (0-100)
0x05	1	MEDITATION eSense(0-100)
0x06	1	8BIT_RAW Wave value (0-255)
0x07	1	RAW_MARKER Section start
0x80	2	RAW Wave Value
0x81	32	EEG_POWER: eight big-endian 4 byte floating point values representing the bands (delta, theta, low-alpha etc.)
0x83	24	ASIC_EEG_POWER: eight big endian 3-byte unsigned integer values representing delta, theta etc.
0x86	2	RRINTERVAL: two byte big endian unsigned integer representing the milliseconds between two R-peaks
0x55	-	Not used (reserved for [EXCODE])
0xAA	-	Not used (reserved for [SYNC])

Table 2. Data stream protocol from the NeuroSky Mindwave Mobile

A parser was written in Java that extracts the information that is used in the project and passed along to any subscriber listeners to this device.

This piece of software is packaged as an agent which links into the VECSED system. On start-up it initializes communication with the EEG hardware and the VECSED server supplying identifying information and necessary handshake. It can then be communicated with and the stream read by any device in the real or virtual world which joins the VECSED network.

An experiment was performed to check the stream and its software agent could be communicated with inside the virtual world. A beacon was created in the virtual world which responded with a change of color depending on the incoming stream. This worked well, changing very quickly in response to changes in the EEG.

7.3 Head Mounted Display Immersion – Oculus Rift and Google Cardboard

To increase the sense of immersion a VR headset (or HMD, head mounted display) was used. Many headsets are being developed but two of the most popular are Oculus Rift and the somewhat home-made Google Cardboard.

Both have some support in the virtual worlds mentioned here; viewers for SL and OpenSim incorporate capabilities for both, or can be adapted. In this project Google Cardboard was used.

7.3.1 Building the complete headset

The headset was composed of several parts:

- The VR visual renderer
- The EEG
- Headphones

It was possible, just to situate all these on to the head at the same time, thanks to the limited coverage on the head of each. For the Google Cardboard mechanism a bought plastic version was used, to hold the phone in place securely. The NeuroSky Mobile Wave was used as the EEG reader due to its compactness and wireless capabilities. Finally, a good set of high quality headphones complete the head gear.

7.3.2 Biofeedback – and initial tests

The list of our inducing agents is as follows: Stroboscopic based elements, Ganzfeld lighting effects, Synchronized audio patterns (monaural, binaural and isochronic beats), Embedded audio patterns (the modulation of sound tracks or soundscapes not necessarily obvious to the user) and spoken or guided techniques. These offer interesting ideas for objects that can be developed inside a virtual world.

A simple “virtual environment pod” was created which changed its color at given program rates. When inside the pod and with the VR headset active the effect was similar to the sound and light machines and rates of pulsing could be set, which would give a Ganzfeld effect.

The EEG stream receiver was connected to the pod via object messaging, available in LSL.

A biofeedback mechanism was added whereby the pulsing would lead the incoming EEG in the appropriate direction (toward a particular state) but only change if the EEG was following and correct itself as it went.

The Ganzfeld mode of the pod was relatively easy to incorporate as all that was required was a functional control over the speed, color and type of color change over time. The software for the pod allowed user defined programs to be stored, similar to the mind machines. In effect these were simply a data store of timing values, rate of flash and duration for specific sections.

The next step was addition of synchronized basic sound pulses to match the field color changes and strobes. This was done by adding another virtual object (yet another agent in the VECSED system) which played in sync, appropriate sound pulses. It should be noted here that it may have been possible to incorporate the sound player within the pod itself but for the sake of modularity it was thought to split this functionality off to an entirely separate object. To create a sync which was in time, the pod and sound object did handshake by sending messages at intervals.

To extend this, a stream receiver was added which accepted an incoming audio stream. The idea here was to create an auditory soundscape which could be “environmental” so, rainforest or rain etc. This agent linked into VECSED and an audio stream player was linked in to cycle a long sample of sound.

The next stimulus device to be developed was a more “directed” strobe mechanism – a moving strobe that can be split to present a synchronized lightshow. Figure 4 shows the biofeedback loop occurring which encapsulates the system.

8 Final developments of the pod

The pod has several ways of being operated. In the first mode it can simply track the users EEG with correspondences made between particular states and colors. In the second mode, a particular program is run which will attempt to induce the user toward a specific state. Here, the concept of the "scene" was developed further as a programming tool. A scene is a specific set of visual and audio cues which induce, or at least take the user toward a particular brain state. An example may be a scene which aims at concentration and involves the user stepping on counted bricks in a sequence.

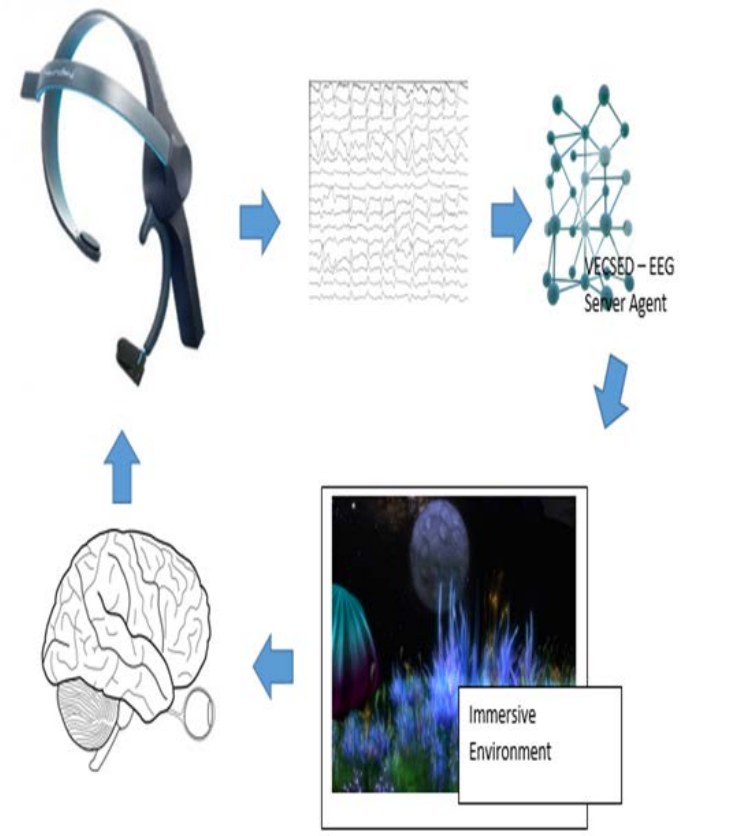

Fig 4. System diagram showing feedback loop between adaptive environment and user

8.1 Programming language

A programming language was developed for the objects which function within the virtual world. This programming language allowed the sequencing of events and loading of particular colors and attributes, textures and media streams within the pod. At its most simple a program could be made to load a particular scene and cycle through various control options until a specific EEG state is reached. This could be as simple as activating a 3D space Ganzfeld effect, pulsing until alpha wave is predominant and then either holding for a period or changing to a new pattern. This allows for an adaptive environment.

8.2 Initial Tests with the full system

Once the full system was operating, more meaningful tests were created toward the primary goal – exploration of the meditative state using virtual reality. A ball was created from the particle type within SL, this expanded in size as one of the EEG attributes increased using red for attention and blue for meditation.

Yet another experiment involved the creation of two 3D animations, a complex “mechanical” set of objects which moved as a progression, the other, being more liquid and surreal. These could be interacted with using the avatar, or simply viewed. Again the ball was used to indicate attention and meditation states and it could be seen to be dominated by the attention waveform for the mechanical progression or more meditative for the surreal experiment.

8.3 Reflecting the user

The developed, adaptive pod, with corresponding repertoire for all the states possible was set up initially to reflect the user’s state. When initialized into SL the pod forms itself and all tools that it requires to function, such as the virtual process devices which communicate via VECSED. A process known as the palette is initialized which can change the color of the environment, media output to walls, audio and other necessary functionality.

With the avatar standing in the pod and the user in the real world with all the headset items (EEG, headphones and display goggles). The EEG signal is fed into the VECSED system and processed. The pod’s processes access the palette and depending on the program running selects an environment which reflects the user’s incoming data-stream relating to the brain-wave pattern. The program could reflect this in:

- Environment (the pod) colors
- Textures within the environment
- Images and video
- Audio

8.4 Inducing states

With the reflection mechanism working, further experiments were necessary to actually manipulate the user toward specific states.

The reflection exercises utilized palettes which activated when a state was reached; here they are used within scenes to reach particular goal or way-point. As well as these palettes, more complex objects were developed which were task oriented:

- Meditation object (abstract, soothing, tending toward “hypnotic”)
- Concentration object (tasks involving focus such as stepping, counting or basic visual analysis)

Both of these objects are instantiated within the virtual world on demand and a selection made to utilize any of their sub-tasks. The concentration object included stepping stones, target focus and calculation. The meditation object included elements which were more abstract in type, utilizing textures, sounds, video and images.

Refinements were made in the objects and programmed environment to integrate the known inducing agents mentioned so far:

- Ganzfeld lighting
- Stroboscopic elements
- Synchronized audio patterns (monaural, binaural and isochronic beats)
- Embedding of audio (and the various modulation possibilities)

These were relatively easy to implement within the virtual worlds of SL and OpenSim due to their completeness, flexibility and power of expression with the programming language (LSL). The virtual environmental pod itself was made so elements could be built-in such as the Ganzfeld capability. It could also strobe.

Sound in the virtual worlds used could be sample-based or incoming streams. An object was created which could handle either of these possibilities and therefore act as an audio interface. The capacity to play samples is limited to some extent due to the size, although for most purposes it is simple cycling of tones used in any case (for example, square wave audio trains). More complex sounds, such as environmental backgrounds or speech track can be streamed into the world. A server database of stored sound was connected through and could be called up as required. The server could store various assets such as video, sound or other media in the database which allows for a complex library. The environmental pod therefore could send a message to the interface object to call up an appropriate resource, when required, for rendering or playback.

Other media objects allowed their surfaces to present particular images or video, again streamed from the server or held locally.

With these capabilities, the virtual environmental pod becomes a fully functioning 3D light and sound synthesizer, capable of either reflecting the user's EEG or taking part in the biofeedback loop and reacting to it.

8.5 Programming for scenes

More advanced techniques were required for scenes, where the user is taken on a journey through various brain states, watching the EEG stabilize in a target range before gently moving to the next way-point in the scenes mapping.

A meta-programming language was developed to control and re-create scenes. This language was parsed by the main system within the environmental pod which then sent messages out to the listening instantiated objects. A simple program might be the creation of a scene with appropriate palette and cycle until a given state is reached, an example of which is shown in figure 5.

```
// instantiate scene "focus ball" and initiate animation/sound
// sequence
load scene "focus ball";
repeat
  // set initial ball state
  scene element["ball".message["blue"]];

  // wait until the incoming EEG stream predominantly what
  // is required
  wait until eegstream(WAVE) == BETA;

  // State achieved set ball to red
  scene element["ball"].message["red"];

  wait until eegstream(WAVE) != BETA;
until FINISH;
```

Fig. 5. Simple initial feedback loop with system

Only a small sample of individuals were tested – the focus for this project was to develop the technical capability and provide a suitable environment for experimentation and further research. The results show that the system, as it is, can induce individuals fairly easily into meditative states (along with others, such as attention/focus). A noticeable aspect was not just the reaching of a state but the stabilization once achieved which was something the system was particularly good at compared to other means, such as mind machines. Figure 6 shows a typical induction session after a relatively short period of 3 minutes.

Mind machines, as sold commercially, do not react to the user they simply execute a light and sound show for the user, who may drift around the EEG spectrum somewhat. The virtual environment captures the individual and reacts, tailoring the output intelligently to the user's current state, which it can attempt to manipulate.

In terms of the practical usage of the system there were only a few technical problems. The NeuroSky EEG, for example, can send an invalid data stream at times. This was found to be due to lack of a complete contact with the ear of the user via the clip and therefore a lack of a reference earth from a "floating connection". A solution to this seemed to be to dampen the lobe a little to help the connection. Aside from this the eSense™ values were very stable and the fact that a lot of the number crunching could be done on the ASIC chip helped matters. The values seemed to be very accurate at deducing the focused and meditative states, though it would be interesting to see the means by which they derive what constitutes a meditation state (for as has been described, there are

many types). This is not a real problem as other values can be used, as they were here, in the various bands to determine a particular state, rather than relying on the two predefined variables for attention and meditation.

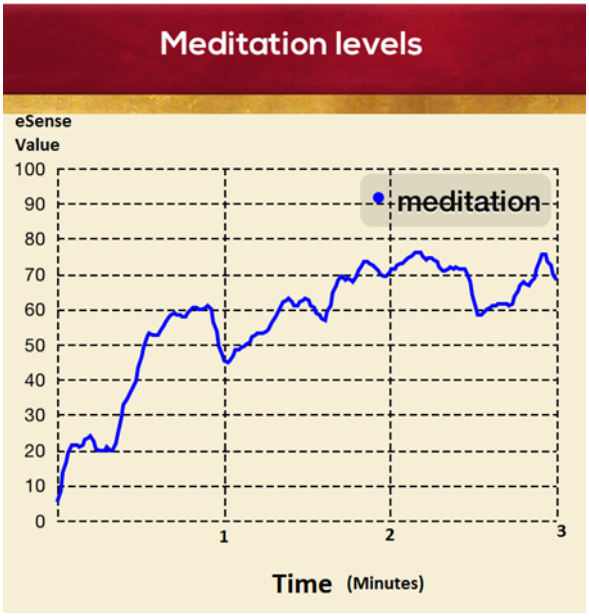

Fig. 6. Showing initial induction into “meditative” state after 3 minutes.

9 Future Scope

The system presented here is a merged reality system operating in both the real world and the virtual. It is an intriguing area with many possibilities for development and experimentation. The biofeedback mechanism within the virtual is novel and stable, presenting good initial studies of how an intelligent system can be built in synergy with the human brain.

The use of Google Cardboard to add depth of immersion with the virtual world appears to deepen the experience of the user. Other headsets could be used such as Oculus Rift and the Microsoft HoloLens. More work could be done to see how performed tasks in the virtual environment by the user affects the EEG, while attempting meditative or concentrative tasks.

It may be possible to integrate Augmented Reality aspects into this system without too much alteration of the hardware and software set-up.

Other virtual environments, such as those already mentioned, High Fidelity and Project Sansar, should offer even greater frame rates and other interactivity to extend the experience. The system could easily be adapted to work in these.

These kind of systems could be used in the training of individuals, or for treatment of particular disorders, such as post-traumatic stress disorder [47].

10 Conclusion

The greater the immersion in virtual worlds the easier it seems to become to utilize the techniques and technologies developed here toward specific brain states. Hardware technology has also developed to the extent that headsets can be developed which are basically wireless and extremely fast to cope with the processing required. These technologies now go beyond the sound and light machines and create the isolation and immersion necessary for exploring artificially induced states.

This work has realized the following:

- The virtual environment can be made to be responsive to a user’s brain states
- Such a system can also be made to induce specific target states with intelligent biofeedback mechanisms

Further work in this area can be carried out to study the effects on individuals at greater depth and technologies refined with the information gained, as data is collected.

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