A Study of the Effects of Acoustic Phenomena and Their Possible Use in Multimedia

Submitted in Partial Fulfilment of the Requirements for Msc in Multimedia Systems

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Declaration of Submission

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Summary

This thesis investigates the effects that certain acoustic phenomena, such as binaural beats and infrasound, can have on people. It reviews ways in which sound technology and acoustic phenomena have previously been implemented in multimedia and the arts, and also suggests new ways to harness the power of a sound that is generally outside the range of human hearing.

The first chapter explores the history of sound in multimedia and the arts, using film and noise music to trace the early days of sound technology, pointing out potentially powerful recording techniques such as binaural recording and holophonics that, although not new technologies, have not yet been fully realised.

In the second chapter, binaural beats are thoroughly investigated in terms of the history and discovery of binaural beats, how binaural beats work in the brain, reviews of several experiments, and an interview with a musician who uses binaural beats. The conclusion of this thesis is that binaural beats certainly can have an impact on a person's life in assisting with learning difficulties, sleep disorders, attention disorders and memory retention. These areas may be improved upon whether or not a person has one of those disorders. Possible applications in multimedia could include learning software, artistic multimedia installations and sound art. However, binaural beats are no miracle cure; they do not work for everyone, they may take time to adjust to, and the results can be somewhat subtle. The more successful applications of binaural beats would appear to be ones that are less magnanimous in their claims, such as an aid to sleep induction.

The third chapter deals with infrasound. Like binaural beats, infrasound does not affect everyone - some people are much more susceptible than others, but when infrasound does have an effect it seems to have a greater impact than binaural beats and the effect is not only psychological but physiological. Increased heart rate, cold shivers, visual distortion, feelings of fear, sorrow, and disconcertment are all possible effects of infrasound that have much potential for use in multimedia and the arts, especially for films and computer games in the horror genre where such feelings are generally exploited. The eerie effects

of infrasound could also be used to enhance sound art and live music performances. This thesis investigates one concert and large-scale experiment where infrasound played a huge part. A scientist from the National Acoustics Laboratory, who built the infrasonic generator, took part in an interview for the purpose of this thesis.

The fourth chapter investigates the past, present and future of acoustic weapons, in order to try and separate fact from myth and unearth the true potential power of the effects of sound on people. It illustrates cases where similar technology has already been used by industrial bands like Throbbing Gristle and electronic acts like Pan Sonic.

Overall, this thesis contains several examples where acoustic phenomena have already been a successful part of multimedia and the arts, but goes on to point out that they have a much bigger potential. This thesis even explores the idea that acoustic phenomena could have played a huge role in Neolithic times and it may just be a lost art that is being overlooked in modern times.

Abstract

This thesis investigates the many types of acoustic phenomena and the affects they can have on people, with a view to their possible use in multimedia. In particular, it scrutinises all aspects of binaural beats, infrasound and acoustic weapons to determine the true effects they can have on people. Throughout this thesis, examples are given where multimedia has benefited from these acoustic phenomena, and it gives further suggestions for their use in both practical and artistic applications of multimedia.

Acknowledgements

The author wishes to thank Nicholas Ward, project supervisor, for his expertise and guidance, Richard Lord of the National Physical Laboratory for answering questions about infrasound and Magnetize for answering questions about the use of binaural beats in his music.

Dedicated with love, for my mother Eileen Braine.

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CHAPTER 1

INTRODUCTION

The psychological and physical effects of sound have been known since the existence of man. Tribal drums have been used to create hypnotic states, war cries have been used to instil terror, and ancient priests have used sound to portray supernatural powers at ceremonies. In modern times, ultrasound and infrasound are used in modern medical technology. There has been much research into acoustic weapons, and sonic devices are being used as non-lethal weapons to control rioting crowds.

In the last two decades a new branch of neuroscience has been investigating exciting ways that we can change our brainwaves. One of the methods for doing so can be achieved by listening to special combinations of sounds called binaural beats.

Infrasound can be produced by a wide range of sources such as thunder, air ventilators and whales and can have strange effects on people, such as nausea and hallucinations.

We are starting to understand and gain control of many of these acoustic phenomena. The effects that music can have on people are interesting, but this thesis explores the many kinds of acoustic phenomena that aren't so well known. It then goes on to investigate the effects these phenomena have on people, and shows examples of how they have been used in various disciplines of multimedia. Further to this, this thesis shows that much of the technology available to create these effects is not realising its potential in multimedia.

1.1 A brief history of sound technology in the arts

At its most basic definition, multimedia is a collection of text, sound and images. There is interactive multimedia, such as CD-ROMs and websites, and non-interactive multimedia such as cinema. This chapter traces a brief history of sound technology in multimedia, by looking at how it has progressed through the history of cinema. Cinema sound has been a precursor to much sound technology that has since been integrated into multimedia technologies such as Dolby surround in computer games. It is also worth noting that a cinema would be the ideal venue for experiencing much of the acoustic phenomena discussed in this thesis. For example, the effects of infrasound are best experienced over a high quality sound system that is capable of high levels of low frequency sound.

Sound has always played an important yet somewhat undermined role in multimedia and cinema. To highlight the secondary role that sound has taken, consider how people discuss films. We say that we are going to "see" or "watch" a film, almost dismissing one half of the audio-visual experience. Films are also called 'movies' rather than 'talkies'. This may just be a reflection on how we witness the world in general; in Western society, we cannot testify that we have truly witnessed an incident unless we have seen it take place rather than just heard it. Some cultures do place sound as the most superior of the senses. The Umeda people of Papua New Guinea are one such culture. They establish the occurrence of an event by saying they have heard it rather than saying that they have seen it[1].

1.2 Films

1.2.1 Introduction

Even before the age of the 'talkies', cinemas employed sound effects men called drummers to create live sound effects using very basic sound effect 'machines'. There was much debate in the 1920s about whether there was any need for these sound effects and if so, how to use them appropriately. This debate was an important one as it laid the groundwork for the theory and practice of sound technology in films for the next eight decades[2].

There were various technologies in the early 1920s developed to properly implement sound into films. Along with sound quality and volume, one of the main problems to overcome was the synchronisation of image and sound. In 1923, Lee De Forest used a system that photographically recorded the sound track onto film, and then the Western Electric company improved the system by using electronic condenser microphones and electronic amplification of the sound, which meant that recordings could be played over loudspeakers at any desired volume.

'Talkies' slowly revolutionised the film industry but take-up was slow at first. Then in 1927, Al Jolson appeared in the 'The Jazz Singer'. This was the first full-length talkie to feature a Hollywood star. There was a huge demand for this musical. The level of quality in cinematic sound was still poor though and there was not much improvement over the next two decades.

1.2.2 The Dolby era

In the 1970s and 1980s a new technology arrived that was developed by Ray Dolby and his company to improve sound quality for the music and film industry. Dolby would set a standard of quality that would carry right through the next thirty years for not only cinema but also home entertainment, computer games, and almost any form of entertainment that involved high quality sound.

Before setting up his own company, Dolby worked for Ampex who developed the first magnetic theatre sound system in 1954. This system included the first practical synchroniser. Initially interested in noise reduction, for both music and film sound, Dolby developed a process that amplified quiet signals while the overall signal was very quiet, and put the signal through a strong limiting process to amplify the low-level signal.

This 'Dolby A' noise reduction was hugely popular in the music industry. Then in the late 1960s Dolby began to develop the 'Dolby A' professional system for use in cinemas. This would reduce hiss, allowing sound tracks to extend their frequency range. At first, the film industry was apprehensive about adopting this new technology, so Dolby further developed the system to create an economically viable stereo system. The term 'stereo' did not mean then what it means now - a simple left and right channel system. Dolby Stereo actually comprised three sound sources - left, right and centre with an extra fourth channel for non-directional surround sound. In the meantime, the development of sound technologies, such as boom microphones and cameras that were designed to emit less noise from their motors, increased the ability to capture sound more effectively.

Cinema owners began to see this new technology as a way to compete with television. By the mid 1970s, all the necessary technology was in place but the take-up was still slow. Only a few cinemas employed the new system. In 1971, Stanley Kubrick's 'A Clockwork Orange' was the first feature length film to use Dolby sound but as sound effects didn't play a huge role in the film, it did not truly demonstrate the power of Dolby. Just as talkies had relied on a musical to showcase a new technology, Dolby required a film where sound was an important element to demonstrate the true potential of Dolby Stereo. 'Star Wars' arrived at just the right moment for Dolby. George Lucas was one of several young filmmakers keen to utilise every opportunity that new technology had to offer. Lucas also recognised the importance of sound in cinema and was eager to make the most of Dolby Stereo.

Other filmmakers were also keen to use Dolby. In 1997, Stephen Spielberg used Dolby Stereo to great effect with 'Close encounters of a third kind'. By 2005, 70,000 cinema

screens in the world were using the Dolby system and 12,000 films had used a soundtrack encoded with Dolby technology. In the early 1980s, George Lucas and the director of technology at Lucasfilm, Tom Holman, began to implement the THX sound system. The THX system was a set of cinema standards that would ensure a movie would sound as it was intended to sound.

By the early 1990s, three companies, Dolby, Sony and Matshushita, were developing digital sound systems. Three appeared on the market around the same time - Dolby Digital, DTS (Digital Theatre Sound), and SDDS (Sony Dynamic Digital Sound). Dolby's system, now commonly known as 5.1 had six channels that consisted of three front channels, two rear surround channels and a subwoofer channel. SDDS used eight channels but to allow compatibility with other systems, these were eventually scaled down to five channels. By 1995 Fox, Paramount and Warner had adopted an all-digital policy.

The 5.1 system came from a cinematic tradition in which the screen was the most important focus of attention and the audience should not be diverted from the screen. So the rear surround speakers were only used for low background sound. In recent years, at the request of modern sound designers, the latest technology, Dolby and Lucasfilm have developed is a 6.1 system, where there is an even amount of channels for the front and the back.

In his book[3] 'The Dolby Era', Gianluca Sergi has this to say about Dolby: "Dolby's achievement goes considerably further than a technological shake-up. In the 1970s and early 1980s, Dolby achieved nothing less than a comprehensive industry-wide transformation, from studio attitudes to sound, filtering through to filmmakers' creative use of sound and audience expectations."

1.3 Beyond Dolby

1.3.1 Binaural recording

There are existing technologies that could greatly enhance films and other multimedia but have never really been used that much. Binaural recording is a method of recording that tries to duplicate how our ears work by using a special microphone set up. Two microphones are placed a head width apart from each other, facing opposite directions. The resulting recording is more spatially realistic. It has become a popular form of recording among hobbyists who record nature but has not been used much in music or multimedia except in a few instances such as Pearl Jam's 'Binaural' and Psychic TV's 'Dreams Less Sweet'.

People sometimes think that binaural recordings are the same as simple stereo recordings but the technique and the result are noticeably different. Binaural recording are also sometimes mixed up with binaural beats which are entirely different (see chapter 3, binaural beats). One thing they do have in common is that binaural beats and binaural recordings are best experienced while listening to headphones.

1.3.2 Holophonics

Although surround sound realistically portrays sound to the left and right, and sound in front of us and behind us, in real life we don't process sounds on the x-axis alone. Surround sound does not deal with sounds that come from above or below which would truly capture the 360 degrees that we hear with.

'Holophonics' is a technology that can capture all three dimensions realistically. It was developed and patented in the early 1980s by Umberto Maggi, a musical technician. Holophonic recording is more complicated than binaural or stereo recording. It uses a system where microcomputers detect and define the spatial position of a sound as it is being recorded. It is based on a similar theory to holographic imaging. A new company called Holophonic has bought the patent for the technology and is currently trying to

break the home entertainment market. A few musicians have already used holophonic recordings such as Pink Floyd for their 'Final Cut' album.

Holophony has to be heard to be believed. It is eerie in its reality. One immediately questions the idea that electronically reproduced sound only exists on an x-axis. Holophony has a huge potential for multimedia, especially in the gaming industry or multimedia art, or noise art that involves the participant to wear headphones, although it has hard to determine just how available the technology is.

1.3.3 Infrasound

Infrasound is defined as sound that is too low for the human ear to detect. Infrasound can have odd effects on people, with feelings such as fear and sorrow, and physical manifestations such as nausea and hallucinations reported. These effects could be harnessed for use in films, music or multimedia to influence audience emotion.

In 2002, a film called 'Irreversible' debuted in Cannes. The opening scenes were brutally violent and to instil even stronger feelings of disgust, the filmmakers merged a low frequency sound of 28 Hertz (Hz). So powerful was the effect that a lot of the audience walked out in disgust and many felt physically ill.

This is the kind of acoustic phenomenon that forms the basis of this thesis. Infrasound and low frequency sound will be discussed in great detail in Chapter 4.

After a description of infrasound in his sound for film book[4], Tomlinson Holman stated "It has been found that people working in buildings with large amounts of structure-borne noise at 12Hz may become ill from the high level of vibration, and the consequent infrasonic sound. Fortunately, this effect has yet to be exploited by filmmakers". This thesis argues to the contrary that it is due time that the potential of acoustic phenomenon such as infrasound is realised in film and other arts.

1.4 Noise in music

As sound technology in cinema was developing, there were even greater developments in the music world, both in the technology and the attitudes towards what constituted music. Machines and noise were beginning to play a role. In 1911 Balilla Pratella wrote the Manifesto of Futurist music, calling for all futurist music to include "the musical soul of crowds, of great industrial plants, of trains, of automobiles, of airplanes".

Luigi Russolo was one of a group of futurist painters including Umberto Bocciono and Giacomo Balla. He became interested in using noise as a form of music and wrote a manifesto in response to Pratella called 'The Art of Noises' [5]. This was the birth of a musical revolution. Russolo built several noise making machines, which he called *Intonarumori* (see fig 1.1), primitive machines that made a single sound when their handle was turned. In 1917, he assembled an orchestra to perform his *Gran Concerto Futuristico*. Many of the people attending this performance were disgusted by the noise, much like people were at the sound effect drummers ruining their silent movies.

"Let us cross a great modern capital with our ears more alert than our eyes, and we will get enjoyment from distinguishing the eddying of water, air and gas in metal pipes, the grumbling noises that breathe and pulse with indisputable animality, the palpitation of valves, the coming and going of pistons, the howl of mechanical saws, the jolting of a tram on its rails, the cracking of whips, the flapping of curtains and flags."
Luigi Russolo – The Art of Noises.

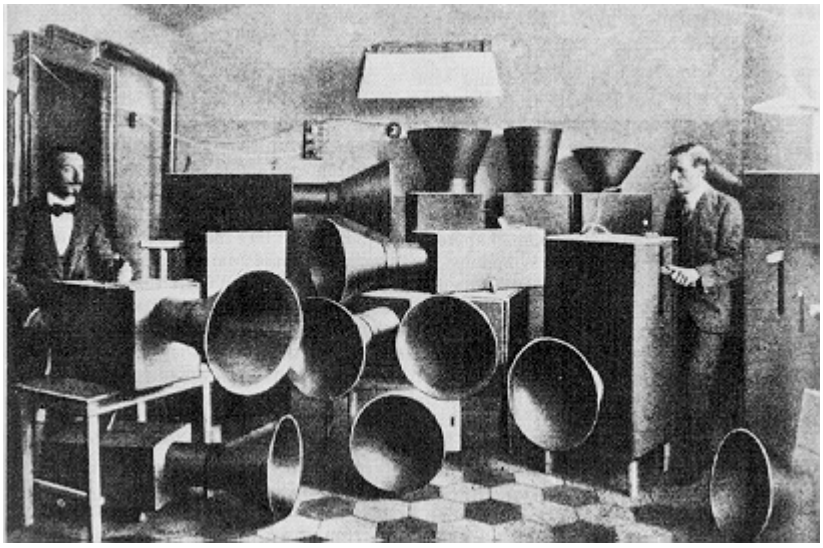

Figure 1 Photo of Russolo with his Intonarumori and his friend, Ugo Piatti

In the 1920s, composers such as Edgard Varèse and George Antheil also began to use mechanical musical instruments influenced by noises from the modern world. In the late 1930s John Cage began experimenting with noise. He used recordings and live broadcasts from radios, television, machines and his audience for compositions. He is still the most renowned of all noise musicians. After World War II, Pierre Schaeffer and Pierre Henry began using tape technology to make music with found sounds and called it *musique concrete*, while Karlheinz Stockhausen began composing with purely electronically generated sound.

Over the years, a multitude of musicians and bands have taken inspiration from the original noise manifestos of Pratella and Russolo. Throbbing Gristle went one step further. They wanted to compose noise that impacted more than just the ears. They wanted to "provoke controlled physical and psychological reactions in the listener. In the metabolic sense the whole body, not just the eardrum[6]." Throbbing Gristle's first experiments with extremely loud noise in their studio caused band members to have tunnel vision and lose their balance and fall over but they didn't have the hardware to carry this out on a concert scale at the time, although alongside, The Swans they were renowned for their extremely loud and physically trembling concerts.

Today noise music and noise art covers a broad spectrum of applications. Pierre Bastien performs with a Meccano Orchestra. A collection of people called Project Dark produce non-vinyl artefacts such as sandpaper, hair, and biscuits to produce noise on turntables. There are many artists who continue to work with sounds from radio transmissions and other found sounds as John Cage originally did, such as Theresa Neuman, Joan Schuman, Mark Vernon and Dublin's Dennis McNulty. There are some more extreme artists such as Merzbow (Masami Akita) who use computers to mix white noise type compositions.

1.5 Outline of this dissertation

This chapter showed the history of sound in multimedia and the arts. Sound itself had a huge impact on film, especially after Dolby radically changed the quality of the system and introduced surround sound. While Dolby was creating technology to get rid of noise, futurists were celebrating the age of noise. Machines, appliances, and all kinds of noise making tools were being used to create music. Throughout the years technologies have emerged that are yet to be appreciated; these include binaural and Holophonic recording. Chapter 1 dealt with technologies within the audible spectrum of sound.

The remaining chapters of this thesis discuss sound that is mostly outside the audible range of hearing, and the resulting acoustic phenomena that can have strange effects on people.

Chapter 3 discusses the phenomenon of binaural beats - how they can be used to change a person's state of consciousness, the history of binaural beats, and a review of experiments carried out with binaural beats. This chapter ends by looking at musicians who use binaural beats in their music.

In Chapter 4, the causes of infrasound, both natural and man-made are discussed in detail. Also included are suggestions on how infrasound could be used in multimedia. At the end of Chapter 4, there is a case study of an infrasonic concert called 'soundless music', which includes an interview with a scientist that was involved in the event.

Chapter 5 looks at the history of acoustic weapons, separating fact from fiction and discussing the true capabilities of sound.

CHAPTER 2

BINAURAL BEATS

Introduction

Binaural beats are created in the brain by combining two pure tones of similar frequency. This can encourage the brain to shift to various psychological states which are useful for various applications; binaural beats can act as a sleep aid, help to focus attention, assist in learning and retention of memories, and induce hypnagogic states similar to meditation. Binaural beats are not the only type of beats, regular audio beats, also known as monaural beats also occur by similar means but there are significant differences between the two.

2.1.1 Monaural beats

If two tones of equal frequency are played simultaneously, the amplitude will double but the frequency will not change. However, if two tones differ by a frequency less than 20Hz, a perceptual phenomenon known as 'beating' occurs. This is perceived as a fluctuation in loudness. When the high point of one sound wave, known as a condensation, meets the high point of the other sound wave, the amplitude is doubled. When the low part of the wave, known as a rarefaction, meets a condensation, or vice versa, the two signals cancel each other out and silence occurs very briefly. The variation between these two states creates an audible beat. For example, if a tone of 400Hz is played simultaneously with a tone of 410Hz, a perceived tone of 405Hz is perceived that rises and falls at a frequency of 10Hz. If the difference between two tones is greater than 20Hz the ear cannot follow the distinct beats and instead hears a rattle-like sound known as roughness [7].

2.1.2 Binaural beats

Binaural beats are different than monaural beats in that the two tones are presented to each ear separately. The sound waves do not actually cancel each other out, as they never physically meet. The beat is synthesised in the brain. For example, similar to monaural beats, if you play a tone with a frequency of 400Hz in the left ear and a tone with a

frequency of 410Hz in the right ear, a binaural beat with the frequency of 10Hz is perceived. The human ear cannot actually hear below 20Hz but the brain artificially creates this 10Hz. There are some other differences between monaural and binaural beats; binaural beats can only be heard when the two carrier tones are comparatively low. The ideal frequency is about 440Hz. Binaural beats also sound slightly more muffled than monaural beats. Another difference is that the brain can perceive binaural beats even if one of the signals is below the threshold of hearing [8].

2.1.3 Entrainment

The theory is that the binaural beats can 'entrain' the brain's natural rhythms to match the artificial frequency introduced by external stimulus and that this can alter a person's state of consciousness and gain benefit from the various applications. This phenomenon is known as a frequency following response (FFR).

Studies with electroencephalographic (EEG) equipment have shown that different brainwave patterns correlate to various states of consciousness and cognitive performance. Entrainment therapy is not unique to binaural beats. Biofeedback researchers have practiced entrainment using expensive EEG and biofeedback systems to treat people suffering from various disorders that register abnormal brainwave patterns. Successful treatment has been carried out on people suffering from depression, sleep disorders, addiction, and attention deficit hyperactive disorder (ADHD), epilepsy, post traumatic stress, paralysis and symptoms of stroke [11].

One of the most cited stories of success with EEG biofeedback was carried out by Peniston and Kulkos in an experiment on a group of alcoholics. 80% of those in the control group who received regular medical treatment relapsed, while 80% of the group who received alpha and theta entrainment showed a full recovery with no signs of depression [10].

The great advantage of using external stimuli such as binaural beats as a form of entrainment is that it is much cheaper and more practical than EEG and biofeedback

equipment. Entrainment with external stimuli can use either visual or auditory stimuli, or a combination of both. Visual entrainment can be achieved by using repetitive lights or images. Auditory entrainment, also known as auditory driving, is achieved by listening to binaural beats.

2.2 Binaural beats and brainwaves

Introduction

Auditory brainstem responses from the left and right ears first meet in the superior olivary nucleus. The superior olivary nucleus plays a number of roles in hearing such as measuring the time difference of arrival of sounds between the ears. It is thought that binaural beats are detected in this part of the brain [8].

The reticular activating system, the part of the brain believed to be the centre of arousal and motivation, reacts to the binaural beats and stimulates the part of the brain that receives sensory input, the cortex, thereby altering arousal states [11].

Brain activity can be measured and recorded by an EEG machine. The resulting traces represent brain waves. There are four major types of brain wave patterns which operate on different frequencies - delta, theta, alpha and beta.

2.2.1 Delta waves

Delta waves oscillate at frequencies ranging from 1 to 3.9Hz so listening to binaural beats within that range can entrain the brain to the delta state which is the slowest frequency of all the brainwave patterns. When we are in a deep sleep, our brain operates in the delta state. It is also thought that our brains release vast amounts of healing growth hormone when we are in the delta state [9].

Entrainment of the brain to the delta stage is thought to be a great sleep aid. The main application of delta waves is for people who suffer from insomnia. EEG measurements have also shown that while people are in deep meditation, their brain operates in the delta state.

2.2.2 Theta waves

Theta waves range from 4 to 7.9Hz. Our brain mostly operates in the theta state during learning and the creation of memories. It is also associated with the relaxed state of the

brain just before sleep occurs. The theta state has also been described as an ideal state for meditation, learning, and creativity. "Theta meditation increases-creativity, enhances learning, reduces stress and awakens intuition and-other extrasensory perception skills"[12].

2.2.3 Alpha waves

Alpha waves range from 8 to 13.9Hz. The Alpha wave was the first recognisable pattern when Hans Berger first studied brain wave patterns in 1924. The Alpha state occurs naturally when a person is awake but fully relaxed, usually with their eyes closed. It is also associated with a state of relaxation while still staying highly alert. The optimum alpha rhythm is a state of relaxed wakefulness in which attention tends to wander, efficiency to carry out routine tasks is enhanced and creative thought is increased[13]. Research has shown that people undergoing meditation, exhibit high levels of low frequency alpha waves [14].

A lot of people who use binaural beats to enter the theta state, attempt to reach states similar to those who have practiced meditation for many years but research indicates that entrainment alone is not enough to reach such sophisticated levels.

2.2.4 Beta waves

Beta waves range from 14 to 30Hz. The beta state is one that is highly alert and focused. It is associated with concentration, problem solving, arousal, alertness and cognition. Higher levels are associated with anxiety and feelings of flight or fight[12].

The recommended method for entrainment with binaural beats is to start with the frequency that matches the state that the brain should be in and then slowly sweep to a new desired state. For example if a person is fully awake and wants to use binaural beats to induce sleep, a suitable path would be to start with theta waves and gradually go down to delta waves. The author of this thesis recorded a CD containing binaural beats that swept from theta to delta and found it induced sleep very quickly. These binaural beats were created with the Brain Wave Generator software[15].

2.3 History of binaural beats and entrainment

2.3.1 Discovery of binaural beats

Binaural beats were originally discovered in 1839 by Heinrich Wilhelm Dove, a Prussian physicist, meteorologist and independent experimenter. Right up until 1915 they were generally misunderstood and only considered to be a slightly different version of monaural beats. Some people thought that each ear was merely hearing sounds intended for the other ear, so to eliminate this likelihood, the two carrier tones were created by tuning forks in separate rooms on either side of the subject who was in a third room in the centre. The sounds were then fed to each ear by long tubes. Today this kind of separation still works best, although the practice is much easier to carry out with the availability of headphones and computer generated tones.

In 1973 Gerald Oster wrote the much cited paper, 'Auditory Beats in the Brain[8]' detailing exactly how they worked. Unlike some of his peers, Oster thought the phenomenon played an important role in human hearing, especially for sound localization. He also thought they might be useful for diagnosing neurological illnesses, as he discovered through experiments that people suffering from Parkinson's disease could not hear Binaural Beats.

2.3.2 Entrainment

The practice of entrainment was not generally known when Oster wrote 'Auditory beats in the brain'. The early history of entrainment is mostly related to visual entrainment. One of the earliest recorded practices was at the start of the twentieth century, when Pierre Janet, a French psychiatrist, discovered that when his patients stared into a flickering light it lowered their depression and hysteria. However, in his book 'Megabrain[9]', Michael Hutchinson muses: "The knowledge that a flickering light can cause mysterious visual hallucinations and alterations in consciousness is something that humans have known since the discovery of fire".

2.3.3 Brainwaves

The breakthrough that the brain operated in different states can mostly be attributed to Hans Berger, a German physiologist, who began studying human electroencephalography in 1920. He was the first person to describe the different brainwave patterns that registered on an EEG. The Alpha wave was first known as a Berger wave[17]. In 1934, Edgar Douglas Adrian and BHC Matthews developed the work further and confirmed Berger's theories[18].

2.3.4 The Monroe Institute

One of the leading researchers and supporters of binaural beats is Dr Robert Monroe. Many available documents on binaural beats originate from his research centre, The Monroe Institute of Applied Sciences. The Monroe Institute also sells a huge range of self-help binaural beat CDs. One has to consider the fact that these documents are not totally independent or unbiased, although the Monroe Institute maintains that it is a non-profit organization.

2.3.5 Hemi-Sync® and Metamusic®

Monroe conducted thousands of studies with binaural beats. One of his conclusions was that when binaural beats were introduced to the brain, both of the hemispheres synchronised to that frequency. He called this hemispheric synchronization, or Hemi-Sync®. He also discovered that layering combinations of binaural beats was much more effective than a single binaural beat.

In the 1980s Monroe started creating tapes with Hemi-Sync® patterns embedded into a musical background, which he called Metamusic®. The tapes were in three different categories, relaxed focus tapes, concentration tapes and sleep tapes. Monroe has also published several books on the topic including, *Journey's Out of the Body*[19], which is in relation to one of the more extravagant claims associated with binaural beats, that of out of body experiences.

2.4 A review of experiments with binaural beats

2.4.1 Tests of the sleep induction technique

Experiment[16]

Hastings recorded brainwave patterns on an EEG machine while the subject was listening to delta wave binaural beats. Researchers at the Langley-Porter and Neuropsychiatric Institute supplied the tape. Doctor Joe Kaniya, director of the Psychophysiology of Consciousness Laboratory monitored the brainwave frequencies of the subject.

Result

The EEG chart showed a typical sleep onset pattern: initial alpha waves, then a slowing of the brain waves, and finally a pattern of stage two and three sleep brain waves in the low theta range. The patterns in the various stages suggested that tape was influencing the subject's state.

Notes

No one seems to mention the possibility that the actual repetitive sound and noise heard while listening to binaural beats can induce sleep. In another experiment[20], workers were monitored in a laboratory where noise from an air conditioner omitted very low frequency noise and infrasound. EEG recordings showed that subjects exposed to the noise displayed a much higher percentage of drowsiness than people who were not exposed to the noise. Their brain was not entrained, as such.

So the onset of sleep while listening to noise will register brainwave patterns associated with sleep. This does not conclude that the phenomena of binaural beats encouraged the onset of sleep or was responsible for the sleep related brainwaves. A blind test should also have been carried out where the subject's brainwaves were measured with premixed tones. This would eliminate the binaural beat effect.

2.4.2 Metamusic with Hemi-Sync® as an adjunct to intervention

Experiment [21]

Varney completed a study of six boys between the ages of 15 and 20 months with Downs Syndrome, neurological disorders or developmental problems. Two of the children listened to 'relaxed focus' Metamusic® with Hemi-Sync® signals for one hour a week for a period of five weeks. The other three children listened to the same music without Hemi-Sync® signals for the same period.

Result

Five of the six children in the study showed improvements. Of the five, the three children who listened to the Metamusic® with Hemi-Sync® signals showed greater improvements, which "appeared to improve the imitation of gestures, facial expressions, two-word phrases and spontaneous use of two-word phrases. Significant increases in attending behaviours and child-initiated interactions also were observed "

2.4.3 Hemi-Sync® on 20 developmentally disabled children

Experiment[22]

Suzanne Evans, carried out a study on 20 children with various feeding disorders due to developmental disabilities such as cerebral palsy and other sensorimotor disorders. Problems with sucking, swallowing and breathing had instilled a major negativity towards eating for these children. Mealtimes were extremely anxious experiences for both parents and child. Evans began a treatment of therapy involving Hemi-Sync® music at feeding times to try to calm the children and focus their attention on the task. Evans is the founder of *New Visions*, which provides continuing education and therapy services to professionals and parents working with infants and children who have feeding, swallowing, oral-motor, and pre-speech problems

Result

- Two of the children responded to the music negatively and it was discontinued.
- Three of the children showed minimal inconsistent changes.
- Fifteen of the children showed positive changes in the behaviour, including improved focus of attention, increased physical relaxation, improvement in sensory coordination, and a reduction in fearfulness.

2.4.4 Investigation into the effect of binaural beats on Human Memory

The Experiment[23]

Richard Cauley Kennerly carried out tests on 50 students. The experimental group contained 27 students who listened to a tape containing music that was embedded with binaural beats from the beta range. The control group of 23 students listened to the same music but without the binaural beats. Both groups performed four learning tasks while listening to the tapes. There was a free recall test, a German word recognition test, a digit symbol test and a digit span test.

Results

The following table shows the mean scores from the four tests.

	Experimental group	**Control group**
Word list free recall	15.93	14.00
Word list recognition	15.04	12.61
Digit symbol test	11.44	09.46
Digit span test	9.85	7.69

Figure 2 Table showing results of binaural beats on memory

Kennerly concluded that it was reasonable to infer that beta-frequency binaural beats are helpful for individuals seeking help in free recall memory, attention and completion of routine tasks and went on to say that they could also be useful for people suffering from Attention Deficit Hyperactivity Disorder.

2.4.5 Binaural beats affect vigilance, performance and Mood

The experiment[24]

Lane et al studied twenty nine volunteers to assess vigilance to a repetitive task and to assess mood assessment during the task. One group listened to binaural beats in the beta range and a second group listened to binaural beats in the theta range. The task was to detect a consecutively repeated capital letter displayed on a computer screen.

Results

Participants who listened to binaural beats in the beta range detected a significantly larger number of targets. Lane et al concluded that listening to binaural beats in the beta range during a 30 minute vigilance task can affect both the task performance and the changes in mood associated with the task.

Lane et al noted the potential application for jobs where attention and focus is essential such as long distance driving and air traffic control.

2.4.6 The effect of binaural auditory beats on the EEG of the human brain

The Experiment[25]

The Beta EEG of four subjects was measured while listening to a binaural beat of 20Hz to see if the brain patterns would shift to that frequency. The four subjects were connected to the BioPac Pro interface via electrodes placed on the scalp.

Result

There was no significant effect on any of the four subjects. A note in the experiment thought it was interesting to note that "the bulk of research done in this field is performed by the Monroe Institute.

Notes

It is not clear in this experiment whether the frequencies were presented to the ear separately or not. Some of the text and diagrams in the paper suggest that the tones may have been mixed before entering the ear, thus a true binaural beat was never presented to the subjects. Background text did indicate knowledge of the separate ear method but that was taken directly from another paper.

2.5 Artists using binaural beats

A small number of musicians, such as Michael Mantra, Boards of Canada and The Anti-Group Conspiracy, have used binaural beats in their music. Boards of Canada have released beautiful, cutting edge electronic music to worldwide critical acclaim. There is also a huge aura of mystery around their music, promoting debate about hidden messages, religious iconography and subliminal messages, so it seems fitting that they also dabble with binaural beats. The Anti-group Conspiracy released a record called 'Teste Tones', which included tracks with binaural beats that were given obvious titles to reflect their contents – such as 'Audio Alpha Activity' and 'Accelerated Audio Alpha Activity'.

Another artist who has been using binaural beats in his music is a Dublin based musician called Magnetize who first heard about binaural beats after reading an interview with Phill Niblock. Niblock was describing how he used layers of instruments with mismatched frequencies to try to disorientate the listener. Magnetize researched the theory further and became fascinated with the idea of brainwave entrainment using binaural beats to produce a marked psychological response. While working with binaural beats, he experienced time distortion and found it beneficial for deep meditation and also found that binaural beats can make you feel sleepy. His recommendation for binaural beats is to listen to them either on headphones or very loudly on speakers.

His recent release for Rimbaud Records called 'Biome' featured elements of binaural beats and they featured in a recent live performance. The effects of binaural beats are hard to achieve in a live situation though. They are most effective in a perfect stereo setup such as headphones. "Ideally I would have liked a quadraphonic setup with each oscillator having its own output and each of the speakers set up in the four corners of the room. However, there were a few practical problems with that; you would need the audience to sit dead centre for that to work properly and the room was too small and they only had a stereo setup. So we just used the main stereo pair that sit above the stage."

See Appendix A to read the full interview with Magnetize.

2.6 Summary

This chapter discussed the history and discovery, and science and application of binaural beats. Binaural beats can be used to entrain a person into certain brain states such as alpha, beta, theta and delta which are associated with various levels of cognitions, and states of consciousness. They can be used to help people sleep, they can be used to focus a person's attention during study and they can be used to induce meditative and hypnotic states.

Various experiments and anecdotal evidence suggest that binaural beats can have a favourable impact on various aspects of a person's life. Possible applications in multimedia could include learning software, sound art, and artistic multimedia installations. The effects of binaural beats do not work for everyone and can be very subtle for some others. It seems that the most noticeable employment is as a sleep aid although it is quite possible that the repetitive noise of binaural beats could also influence sleep regardless of any brainwave entrainment. The author of this paper found listening to binaural beats quickly induced a state of sleep but not necessarily with binaural beats that were supposed to achieve that effect.

Entrainment by binaural beats is an area that still needs more independent investigation with more subjects taking part in bigger experiments. Previous experiments using binaural beats to try and improve cognition, focus attention, and improve of memory have proved successful with a lot of people, so similar applications could be applied to multimedia for e-learning software and training CD-ROMs or DVDs. The author of this thesis worked for four years in the e-learning industry and knows that it is difficult to maintain a user's attention at times when interaction with the software is minimal. There is already one company, called Tour Tempo, who sells a golf instruction audio CD embedded with binaural beats[26]. With multimedia art installations or sound art, theta waves could be used to create a more hypnotic experience. One disadvantage with binaural beats is that they need headphones for a greater chance of success.

CHAPTER 3

INFRASOUND AND LOW FREQUENCY NOISE

3.1 Introduction

Infrasound is sound within a frequency range that is too low for the human ear to hear. Any sound below 20Hz is classed as infrasound. However it has been discovered that at extreme levels the ear can detect sounds with a frequency even as low as 1Hz. Infrasound is naturally produced by volcanoes, wind, surf and storms. It can also be artificially produced by jet engines, industrial machinery, ventilation machinery, trains, wind turbines and even small engines such as car engines. In the natural kingdom, various animals can not only hear infrasound but can use it to their advantage. When hunting, tigers can stun potential victims with a roar of 18Hz; similarly whales use it to shock their prey, while elephants make use of infrasound to communicate across long distances. Infrasound can have extremely adverse effects on people such as headaches, nausea, feelings of fear and hallucinations. As with binaural beats, some people are more susceptible to these affects than others.

Low frequency noise ranges from about 10 to 200Hz. Most of the interesting effects of low frequency occur in the infrasonic range but there is some crossover into the audible range too. Although infrasound does not necessarily produce feelings that would be considered desirable, it still has great potential for use in multimedia. For example, there have been investigations[39], which indicate that a lot of ghost sightings are caused by a nearby infrasonic noise which makes people hallucinate and feel a change in temperature. It seems unbelievable that this anomaly is not being used to greatly heighten the experience of terror in horror films or other genres such as war films and thrillers. The horror genre is also a huge part of the gaming industry so there is huge potential there to use infrasound to make games even scarier.

3.2 History

In 1957 Dr Vladimir Gavreau assembled a research team to develop automatons for military purposes. During this research the group occasionally encountered bouts of nausea which turned out to be infrasound produced by the motor of a badly fitted ventilator. Dr Gavreau and his team focused on researching infrasound with the use of acoustic weaponry (see Chapter 4, Acoustic weapons for more information).

In the 1960s, the National Aeronautics and Space Administration (NASA) scientists carried out detailed research into infrasound and the effects it can have on the human body. They were particularly interested in the effects that low frequencies produced by rocket engines might have on their astronauts. They carried out experiments in low frequency noise chambers and their tests confirmed that infrasound did have physiological effects including headaches, coughing, visual distortion and fatigue.

Some years later, stories concerning infrasound began to appear in newspapers and television. Quite often these stories where somewhat sensational. There were reports that infrasound from car engines was making the drivers feel drunk. Research has since shown that levels of infrasound produced by a car engine, produced no adverse effect on reaction time or levels of concentration[27].

Infrasound has also had its fair share of urban myths. Rumours abound about the 'brown note', a particular frequency that could cause involuntary defecation. This has proven to be untrue. In a section of a report on acoustic weapons regarding unfounded claims[28], Jürgen Altmann stated that "Evidence for bowel spasms and uncontrolled defecation is even scarcer. Among all the literature surveyed for this report, the only hint found was one on "digestive troubles"".

However, infrasound is a respected branch of meteorology. It can be used to measure earthquakes, and infrasonic systems are used by the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization to monitor for infrasonic

explosions and eliminate natural sources from the findings[29]. Similarly, infrasonic devices were used in World War I to detect enemy location by scanning for noises produced by heavy artillery.

3.3 Artificially produced infrasound

A lot of man-made machinery generates infrasound including all forms of transport, pumps, compressors, diesel engines, combustion machinery, air turbulence, and fans. The following table shows some sound sources along with the frequencies and sound pressure they produce[28].

Source	Frequency	Sound Pressure
Industry	5-100	70-110
In car (window closed)	5-100	100
In car (window open)	1-30	120
Jet aircraft (underneath flight path at airport)	10-sev.	1000
Jet engine with afterburner (at runway)	20-800	148
Large rocket, crew compartment	10-2000	135
Large rocket at 1.6 km	1-200	130
Sonic booms	1-100	120-160
Airbag inflation	~ 5 / 500-1000	170
Ship engine room	133	
Blast wave	< 1-100	unlimited
Loudspeaker headset	1-200	146
Whole-body chamber, loudspeakers	2-100	140
Whole-body chamber, piston	0.5-10/30	172/158

Figure 3 Sound sources and their frequencies and sound pressures

3.4 Natural sources of infrasound

Introduction

Many sources of infrasound can be found in nature - exploding meteors, exploding volcanoes, earthquakes, the aurora borealis, severe storms, thunder and the surface of the sea in a storm.

3.4.1 Earthquakes

Prior to earthquakes cracking the earth they emit long infrasonic waves. Some animals can hear these pulses and sense the danger that is ahead. When the great earthquake of Krakatoa occurred, windows were shattered hundreds of miles away by the infrasonic blast. Since then, barometric readings have been used to try and predict the occurrence of earthquakes[30].

3.4.2 Infrasound produced by water

When surf laps against the shore, it produces noise with a frequency of 16Hz. The surface waves of oceans and large lakes produce a similar frequency. The booms of a little understood acoustic phenomenon called the *Barisal Guns* are thought to contain infrasound. These cannon-like booms were often heard near water areas but go by unnoticed in today's noisy world.

Waterfalls also produce infrasound, and many visitors to Niagara Falls have reported feelings of nausea that aren't related to vertigo. Researchers in the Antarctic have also accounted feelings of nausea. Glacial ice is known to produce deep booming sounds, which suggests that as well as these audible noises infrasonic noise may also be produced[30].

3.4.3 Thunder, storms and wind

Thunder, strong wind and violent storms can produce low frequency sounds within the infrasonic range and also within the audible low frequency range. The low frequency rumble of thunder is quite apparent. People who live near areas with highly active jet

streams have reported feelings of weakness and fatigue and even severely upset stomachs. These symptoms might be caused by infrasonic sound generated by wind shear. Areas where mountainous regions may shape the flow of wind might be responsible for such reports.

Infrasound can travel huge distances. In 1967 an investigation was carried out in Chicago with regard to the long-distance effect of infrasound produced by storms. The storms in question were 1500 miles away and no visible signs of the storms were evident in Chicago. Statistics related to traffic accidents[31], school absences, mortality and birth rates[32] were all higher during periods of the storm while Föhn winds created high levels of infrasonic disturbance. The Föhn wind is a dry, warm wind that occurs in mountainous regions.

3.4.4 The Aurora Borealis

The Aurora Borealis produces sounds which can be heard and felt by humans but can not be recorded on electronic devices. The infrasound produced by Aurora does register on sensitive barometric devices though. Auroras are known to make people feel nauseous and irritable. Eskimos have been known to consider Auroras as evil[30].

3.5 The effects of infrasound and low frequency noise on people

There have been numerous research publications that show the adverse effects that low frequency noise can have on people. The biological effects discovered in studies have included vertigo, imbalance, intolerable sensations, incapacitation, disorientation, nausea, vomiting, bowl spasm, resonance and vibration of inner organs, fatigue, apathy and depression, loss of concentration and drowsiness[33.] In another experiment[35], 20 men exposed to infrasound showed significant changes in blood pressure. Similar results with pilots[36] showed that long term exposure to infrasound, decreased alertness and altered perception of time.

Research has been carried out on body vibrations produced by exposure to low frequency noise[38]. Brown, Kyriakides and Leventhall carried out experiments with noise ranging from 3 to 100Hz in a chamber. The main effect experienced was resonance in the chest at

30 to 80Hz which altered the subjects' voices and made them slightly hoarse. This indicated that the resonance occurred in a structural source such as the ribcage rather than within a body cavity such as a lung. In an epidemiological survey of low frequency noise from appliances or near domestic buildings, severely adverse effects were exhibited by those subjected to the noise[34].

One of the most recent studies was carried out in 2004 when the physiological and psychological effects of infrasound were studied. The experiment took place in a large room. Blood pressure and heart rate were measured. A total of ten people took part and were divided into two groups. One of the groups was exposed to 4.10Hz at 120 decibels (dB). The other was exposed to 2.14Hz at 110dB. Of the psychological effects, all felt uncomfortable, no-one felt nauseated or carsick, nine felt ear pressure, six felt headachy and fretful. Five felt tired and troubled. Of the physiological effects there was an average 10% change of heart rate and diastolic pressure. Apart from the effects indicated in the results one of the main conclusions was that different people react to infrasound in different ways.

3.5 Archaeological theories involving infrasound

Archaeologists have recently discovered that some ancient sites have the ability to play strange tricks with sound, resulting in physiological sensations. They believe that Stone Age people had a sophisticated knowledge of acoustics, and these effects were deliberately implemented. Four experts, including a musicologist, an archaeologist and an acoustician, investigated various archaeological sites. One of these sites was a passage grave in the Camster Round, in Scotland. They gathered in the chamber of the tomb, while a musician played a bronze horn. All four felt similar sensations - an excitement in their whole bodies and an intensification of the sound in way that could not be captured by a tape recorder. In a television documentary called "Sounds of the Stone Age"[37], Dr John Purser, a musicologist, said it was "not just an acoustic phenomenon but a whole-body phenomenon."

The team believed that burial rituals took place in chambers like this, and when Neolithic people played instruments or sang, the resonance of the tombs may have caused unusual or disorientating sensations. David Keating, an acoustician, described experiences very similar to Throbbing Gristle's early studio experiences - "It tends to produce effects like dizziness or giddiness and then you would get a feeling of being very uneasy. You feel a very strange effect. You feel nauseous or feel like you're going to fall over". Keating visited a similar passage grave, the chambered mound of Maes Howe in the Orkney Islands and realised that the tomb resembled a Helmholtz resonator.

The Helmholtz resonance is an every-day acoustic phenomenon that can be witnessed when one blows across the top of a bottle. The resonance at the edge of the bottle interacts with the air inside and increases the amplitude of the edge resonance, easily creating a low pitched note from within. Like many other passage graves, Maes Howe, has a spherical chamber that is connected to the outside by a long narrow passageway, so it resembles an enormous bottle on its side. It may have been designed so that wind or thunder blowing over the mouth would cause the chamber to resonate. Similarly, sound generated within the tomb would greatly increase in amplitude.

The presence of a Helmholtz resonance in itself though would not explain the strange effects experienced in the tomb. Aaron Watson and David Keating made some acoustic measurements and found that the tomb had a resonant frequency of 2Hz, a very low infrasound. They also discovered that drums have been found on the Maes Howe site and drums can generate infrasound. They team carried out a reconstructive experiment by drumming in the chamber, and experienced some strange effects. David Keating fell into a strange kind of sleep, "I'd experienced this bizarre situation where my body seemed to have fallen asleep whilst my brain stayed wide awake." It would seem that Stone Age people were capable of manipulating sound. The team went on to stipulate that sound might have been used to bolster the power of an emerging priestly elite. The tombs also had slits that were perfectly aligned to the rising sun at winter solstice. Alongside the acoustic phenomena, priests may have combined light and sound in a powerful display of their supposed power.

Figure 4 Camster Round Cairn - Highland, Scotland

3.6 Paranormal effects of infrasound

3.6.1 The Ghost in the Machine

There has been anecdotal evidence that infrasound causes several effects which when combined could seem like a paranormal experience or more specifically a ghost sighting. These effects include, cold shivers, feelings of anxiety, excessive perspiration, and oscillation of the eyeballs culminating in visual distortion or hallucination. These can all be attributed to infrasound. Vic Tandy, an engineering designer, had first-hand experience of this phenomenon and decided to investigate further[39]. One night he began to feel very anxious and depressed and then sensed a presence in the room. He saw what appeared to be a grey apparition out of the side of his eyes, which terrified him, but as he turned to face it, it vanished. Other co-workers also had experiences of irrational fear and anxiety and the laboratory gained a reputation for being haunted.

The next day while Tandy was working in the laboratory, a piece of metal in a vice began vibrating. After some investigation it was revealed that this was caused by a standing wave in the lab. Standing waves are sound waves that reflect back off surfaces to their original position, so they seem to stay standing where they are rather then dissipating. Tandy calculated that the standing wave was 19Hz. Aaron Watson and David Keating also found standing waves during their archaeological investigations of burial chambers.

Much like the original discovery of infrasound by Dr Gavreau, it turned out that there was a new extraction system installed in the cleaning room at the end of Vic Tandy's lab. When the system was mounted properly all the symptoms it had caused disappeared.

3.6.2 Loch Ness

Infrasound can be caused by ocean or lake surf lapping against the shore. These waves create an infrasonic pitch of 16Hz. The human eye resonates between 15 and 60Hz. Putting these two facts together it would not be unreasonable to postulate that many sightings of the purported loch ness monster may have been caused by infrasonic sounds from the lake itself.

3.7 Artists using infrasound

3.7.1 The Soundless Music project

Introduction

Soundless Music[40] was both a concert and an experiment with infrasound. It took place over two nights in 2003 and was organised by a group of artists, musicians and scientists to test the effects of infrasound. Each concert featured an hour of live piano, electronic music and video installations. The music was interspersed with deep bass tones from an infrasonic generator that was built by the Acoustical Metrology Group from the National Physical Laboratory (NPL). It consisted of a long pipe with a loudspeaker fitted at one end. The 17Hz frequency at which the pipe resonated was determined by its length.

Seven hundred and fifty audience members were asked to fill out a questionnaire relating to how they felt during the performance of four different pieces of music. During the infrasonic performances, there was an increase of 22% in reports of strange feelings such as shivers down the spine, a sense of coldness, and feelings of anxiety.

3.7.1.1 Richard Lord Interview

The project was a collaboration between acoustic engineers from SpaceDog, psychologists from Liverpool Hope University, a musician, and a team from the National Physical Laboratory. NPL's involvement in the project was to advise on possible effects, and to produce and measure the infrasound during the musical experiment. Richard Lord from NPL took part in an interview for the purpose of this thesis; the following is a synopsis of the questions and answers. See Appendix B for the full interview.

The infrasonic generator was built with a low budget in mind and it is quite low-tech. At its most basic description it is a 4.8 meter long drain pipe, with a speaker connected to one end. The length of the pipe dictated the fundamental frequency that the pipe would resonate at, 17.5Hz. A shorter pipe was also used but wasn't totally necessary.

“We had a shorter section of pipe on the back of the speaker in the vague idea that the rear radiated sound would stimulate the fundamental frequency of this shorter section - which would be 35Hz, the first harmonic of our infrasound. The idea being that this would be out of phase and perhaps help to cancel the first harmonic. However, we found that since we drove the pipe at 17.5Hz, the first harmonic was already 50-60 dB down from our fundamental and the short section of pipe wasn't necessary. The pipe worked just as well without it - but became less visually exciting - so the shorter section stayed, and gave us the opportunity to lower the frequency, by moving the position of the speaker - if required.”

The sound was produced by a large diameter speaker driving the air in the pipe at the resonant frequency of the pipe. The speaker was made by a Danish company named Peerless and is one of their ‘Xtra Long Stroke drivers’. The 'Long Stroke' means that the cone is capable of large displacements, without hitting a physical limit, and therefore large amplitudes can be produced.

While working with infrasound the team at NPL have noticed side-effects; typically fatigue type symptoms. During the concert, the team monitored the acoustic level from 10Hz - 20 kHz, and set a limit on 90 dB exposure for the infrasound.

Richard Lord also stated that “infrasound is not really that special. Just think of the annoyance caused by noise in the audio frequency range, or the emotions that can be induced by music.”

When asked about physiological effects such as visual distortion. Lord said that sound pressure levels would have to be very high for the kind of effects to take place.

Figure 5 Richard Lord with the pipe used to generate infrasound

3.7.1.2 Results of the questionnaire

Of the 700 people that attended the concert, 522 took part in the questionnaire. There was a range of unusual feelings reported in the questionnaire. These are some of the words used in the questionnaire to describe feelings at the time the infrasound was playing; ‘strange blend of tranquillity and unease’, ‘a sense of sorrow’, ‘brief moment of anxiety’, ‘excited’, ‘increased heart-rate’, ‘headache’, ‘tingling in neck and shoulders’, ‘nausea’, and a ‘sense of coldness’.

The project was conducted by a multi-disciplinary team, including Sarah Angliss, composer and acoustic engineer; Dr Richard Lord and Dan Simmons, physicists from the National Physical Laboratory; GéNIA, pianist; Ravi Deepres, video artist and psychologists Ciarán O'Keeffe, Liverpool Hope University, and Professor Richard Wiseman, University of Hertfordshire.

3.7.2 Mark Bain

Mark Bain calls himself a *vibration artist* and a *megamedia artist.* The latter indicates the large scale that his work sometimes encompasses, most of which involves connecting oscillators to buildings and other architectural structures such as bridges. Bain tries to tune in to the resonant frequencies of the buildings he works with and often generates high levels of low frequency sound and infrasound.

In one of his pieces 'The Live Room, Transducing Resonant Architecture[41]', small oscillating machines were attached to four of the major columns throughout an exhibition space, to vibrate the concrete at its own resonant frequency. The Live Room generated infrasound throughout the building. Audience members interacted by lying down on the floor to feel the vibrations.

In an interview with Josephine Bosma[42], he spoke about experiences with infrasound in his work. "It does strange things to physiology and psychology of subjects submitted to it. The experiences here at V2 concerning this, were that Andreas Broeckman was complaining of headaches at one point, and Marc Thelosen, the production man had to kind of escape the building because he was getting solidly confused from it."

Figure 6 One of the pillars in the V2 building with an oscillating machine attached

3.8 Summary

As we have seen in this chapter, scientists have known about infrasound for a very long time and its power may even have been used in the Stone Age. It is produced a lot in the natural world and various reports have shown that it even natural occurrences of infrasound such as the Föhn winds can have great effects on people[31].

Infrasound may even be responsible for supernatural experiences such as ghost sightings and the loch ness monster. This chapter also showed that artists like Marc Bain, and those involved in the 'Soundless Music' project, can successfully incorporate infrasound in their art and music.

Although the results are sometimes exaggerated, infrasound can undeniably have strange effects on some people and it has huge potential for use in multimedia and the arts. If we think in terms of art, it does not always make us feel good. Sometimes modern art can shock and disgust us. These are valid criteria. Likewise feelings of fear and unease can be equally exhilarating. Infrasound could be a great tool to inculcate these feelings with such applications as sound art, multimedia art, and noise music. One could even go so far as saying that visual distortion caused by infrasound could make the audience a more active participant.

The potential for film and games is obvious; infrasound could heighten senses of fear and dread in genres that require such an emotional response. One benefit that infrasound has over binaural beats is that it doesn't require headphones but it does need to be experienced on a sound system that is capable of reproducing sound within very low ranges. The author of this thesis did not have any success with trying to produce any odd effects by generating infrasonic tones on a computer based audio system.

CHAPTER 4

ACOUSTIC WEAPONS

4.1 Introduction

This chapter investigates acoustic weapons to better understand the more extreme effects that sound waves can have on humans. This chapter may also act as an indicator as to the levels and types of sound which may be considered hazardous.

Acoustic weapons have been under research in many countries, mainly as non-lethal weapons. Since World War II, acoustic weapons have been discussed both in the media and through hearsay on the Internet to varying degrees of accuracy. Many of these rumours do not stand up to scientific research or further investigation.

4.2 History of acoustic weapons

Dr Vladimir Gavreau, a French robotics researcher, was one of the first people in history to begin researching sound as a weapon. His team of researchers occasionally felt ill during their work, and eventually tracked down the source to a badly fitted air ventilator, which emitted noise with an infrasonic pitch of 7Hz. As Dr Gavreau also worked in the field of military research, this chance occurrence with infrasound spurred him on to further study the effects it can have on humans and also to attempt the creation of acoustic weapons[40].

His first endeavour was to try and emulate the accidental infrasound that the laboratory ventilator produced, but on a grander scale. He built a giant organ with pipes that were six feet wide and 75 feet long. The pipes emitted an infrasonic noise between 3 and 7Hz. The first experiment with the organ nearly destroyed the building in which it was housed. Gavreau and his team were reputedly ill for days afterwards because their body cavities resonated at such a deadly frequency[44].

Another researcher, Dr Zippermeyer worked on a device in Germany which he called a 'sound cannon'. This produced a high-pitched tone that was reputed to be lethal to animals and extremely uncomfortable for humans at a close range[44].

Dr Gavreau and Dr Zippermeyer's machines may have been as deadly as these accounts portray them to be, but that in itself would not make them effective tools of warfare. Sound cannot be propelled over large distances without propagation, and lower frequencies dissipate at a much greater rate. Low frequencies can be reduced by as much as 6dB for each doubling of distance. Even with high frequencies, the sound is spread over a large area as it gets further away from the source. This type of diffraction is known as spherical spreading. Wind, temperature, and absorption by other matter can also reduce the strength of the sound. Add to this the fact it would not be easy to hit a specific target with a sound wave from any great distance.

From more recent times, there were reports in the press[45] about a device called a 'Squawk box', which was allegedly used by the British army in Northern Ireland to dissipate rioting crowds. The device was said to emit two ultrasound frequencies that would create a beat frequency in the ear that was said to be intolerable. This was denied by the British Army and does not stand up to scientific analysis.

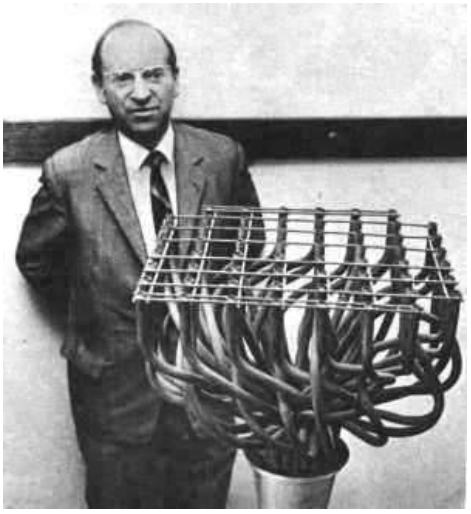

Figure 7 Dr Gavreau and one of his devices

4.3 Official research

The United States Army Armament Research Development and Engineering Centre (ARDEC) and the Los Alamos National Laboratory (LAN) have both been carrying out research into the projection of low-frequency acoustic beams. ARDEC are also researching a device to shoot high-frequency acoustic bullets from an antenna dish[46].

4.4 Effects of sound on people

Introduction

The following sections illustrate the effects that specific ranges of sound can have on people. These findings are based on a variety of experiments as discussed in a paper by Jürgen Altmann[28]. Although it is eight years old at the time of this thesis, the Altmann paper is probably the most comprehensive report on acoustic weapons to date.

4.4.1 Effects of low intensity, low frequency sound

The effects of low intensity, low frequency sound are not relevant as weapons as they only cause annoyance, but they are mentioned in Altman's report. Annoyance occurs at widely different levels from 120dB in motor vehicles to below 60dB in neighbourhoods affected by industrial noises.

4.4.2 Effects of high intensity, low frequency sound on the ear and hearing

This thesis has discussed the potential psychological and physiological effects of infrasound on humans, but it seems our ears can handle infrasound a bit better. The human auditory system appears to be very tolerant to low frequencies, particularly those within the infrasonic range. Pressure sensation is noticed in the ears at about 130dB. As a reference for 130dB, the horn on a train produces a sound at roughly that level. Actual pain occurs in the 50-100Hz at 135dB, below 20Hz pain occurs at 140dB and with a frequency as low as 2Hz pain occurs at 162dB.

4.4.3 Effects of high intensity, low frequency sound on the vestibular system

Exposure to sonic booms between 154dB and 171dB did not lead to adverse effects on the human respiratory system. 50Hz at 150db caused gagging but was found to be bearable. Between 50 and 100Hz caused discomfort in stomach muscles, coughing and

choking. Altman concluded that the strongest respiratory effects will occur in the low audio range, specifically 50 to 100 Hz.

4.4.4 Other effects of low frequency sound

Exposure to low-frequency sound levels (30 to 100Hz) at 150dB caused increased pulse rates, blushing, saliva secretion, and pain on swallowing.

4.4.5 Effects of whole-body vibration caused by low frequency sound

Scientists have ascertained that different body parts resonate at different frequencies. Low frequency sound can cause vibration of the body or different body parts. Below 2Hz the body vibrates as a whole. 4Hz will cause the head to vibrate. 5Hz will cause general discomfort. The voice may warble at 10 to 20Hz, and eye resonances within the head may be responsible for blurred vision between 15Hz and 60Hz. Vibration above 2Hz produces several physiological effects. 1 to 25Hz caused laboured breathing, chest pain and in some conditions, gastrointestinal bleeding. No lasting effects were observed.

4.4.6 Effects of high-intensity, high-frequency and mid range sound

With regards to acoustic weapons one should recall that discomfort in the ear begins at about 120dB and pain occurs over 140db. Ear drum rupture occurs at 160dB.

4.4.7 Non-auditory effects of high-intensity, high-frequency and mid range sound

Scientists researching the effects of jet engines[47] found that at 140dB a sense of disturbance in the equilibrium could be felt. Ground personnel experienced mild dizziness and unsteadiness. They did not experience nausea and did not take any of the effects too seriously, but when an analysing scientist stood near the engines, he experienced “a most unpleasant and disturbing sensation of general instability and weakness”.

At audio frequencies of 90 to 125dB many studies have found short term physiological reactions such as muscle tension, slightly increased heart rate, constriction of skin blood vessels, and eye pupil dilation[48].

4.5 New acoustic weapons

Recent times have seen the emergence of several acoustic devices. Technological advances have furthered the ability to keep sound within a narrower degree of propulsion, which lessens the effects of spherical spreading.

4.5.1 Long Range Acoustic Device

The Long Range Acoustic Device (LRAD) is an acoustic weapon created by the American Technology Corporation[49]. They describe it as "a breakthrough long-range hailing and warning device designed to communicate with authority, affect behaviour and determine intent. It has the unique ability of providing amazing voice and tone clarity in a 15° to 30° beam at distances over 300 meters using only two amps of power. In addition to microphone input, the LRAD can communicate in various languages via the built in MP3 player or Phraselator."

Carl Gruenler, a former employee of the American Technology Corporation said that being within ninety meters of the device is extremely painful, and as a non-lethal weapon its use should be limited to 270 metres[50]. In September 2005, 350 LRAD systems were deployed. They are being used by the United States Navy, the United States Coast Guard, the Military Police and two UK Navy ships[51]. An LRAD was used by Police in California to clear ten people out of a house so they could search it[49].

Figure 8 Californian policeman with an LRAD

4.5.2 Magnetic Acoustic Device (MAD)

A press release for HPV technologies[52] describes their MAD device as "the loudest, longest distance that audible, high fidelity sound has ever projected in the history of sound." After a demonstration, the Los Angeles Sheriff's Department considered using a MAD device as a non-lethal weapon for use in crowd control. Charles Heal, Commander of the Sheriff's Department said "The human brain is sensitive to certain frequencies. We can create the frequencies easily and target a beam of sound to broadcast things that are irritating and thereby crowds or individuals will avoid the sound".

4.5.3 The Scream

The Israeli Army recently demonstrated a new acoustic weapon called The Scream[53]. "The weapon emits a painful burst of sound at a special frequency, targeting the inner ear and causing dizziness and nausea".

In a recent interview on National Public Radio[54], Melissa Block interviewed Dr Malcolm Davis in relation to stories about The Scream. Davis studies future warfare technologies at the Joint Services Command and Staff College in Wiltshire. Block asked why this seemingly simple technology is only being used recently.

"It's simple in concept, complex in execution; in effect what we're talking about is firing acoustic bullets, bullets of sound. To get the desired frequency to actually project a narrow cone of acoustic energy over a fairly extensive distance is what's complex, and that's the reason why it hasn't been used before", replied Davis.

4.6 Summary

This chapter investigated the history of acoustic weapons, and ascertained some facts about the true power of sound over people. Although acoustic weapons are not the devastating tools of warfare that legend would have us believe, there is no doubt that sound can cause extreme discomfort and pain within the infrasonic, audio and ultrasonic ranges.

Research into the area has proved without a doubt that sound can cause such effects as nausea, dizziness, unsteadiness, coughing, choking, gagging, blushing, saliva discretion, warbled voice, visual distortion, blurred vision, laboured breathing, chest pain, gastrointestinal bleeding, muscle tension, discomfort in stomach muscles, increased pulse rates, pain on swallowing, slightly increased heart rate, constriction of skin blood vessels, eye pupil dilation and general discomfort.

This chapter also reviewed modern technology and new acoustic weapons. The technology to propel sound across large distances within a narrow sonic field is advancing, yet the most realistic application for acoustic weapons still appears to be a non-lethal one. The latest batch of devices confirms previous research that acoustic weapons may not be suitable for warfare but may prove to be very useful as a more humane replacement for tear gas and rubber bullets.

From an artistic perspective, similar technology has been used by bands like Throbbing Gristle, The Swans and Pan Sonic to produce equally unpleasant effects, and Jimmy Cauty, formerly of KLF, a renowned musician, artist and prankster apparently made a cow accidentally abort[55] while playing with sonic weaponry. Pan Sonic have always experimented with low frequencies on home-made sine wave generators and played a gig with Cauty's 'Advanced Acoustic Armaments' sound system rigged up on an armoured car[56].

CHAPTER 5

APPLICATION OF ACOUSTIC PHENOMENA IN MULTIMEDIA

E-Learning

Binaural beats can help concentration, focus of attention and memory. One area of multimedia that could benefit greatly from the use of binaural beats is e-learning software. A lot of computer applications that are taught through e-learning software, such as Microsoft Office applications, can be a bit tedious to learn. They usually feature a single voice-over artist who takes the user through the various features of the application, one by one until the user has been shown all functions of the application. This can become very repetitive, and studies have shown that the user's ability to absorb information diminishes over time[57].

Experiments have shown that listening to binaural beats in the theta range can affect vigilance while attending to boring tasks and can also help focus attention[24]. Other experiments have shown that listening to binaural beats in the delta range can help in the retention of memories and completion of routine tasks[23].

These e-learning applications could greatly benefit from the use of binaural beats; a binaural beat that slowly sweeps between the alpha and beta states could be applied to focus the learner's attention on what is being taught, reduce the level of boredom, and improve the chances of retaining what they have learnt. The beats could be embedded in light background music.

Artistic applications in multimedia

There are many gallery installations that are contained within an enclosed room with an audio-visual set up designed to create a certain atmosphere and stir emotions. Typically the sounds are drones or hums or minimal electronic music. The application of

infrasound at these installations could heighten the sense of emotions and the atmosphere in the room.

Similarly, the use of binaural beats within a small space, accompanied by relaxing and soothing audio and visual displays could enhance a multimedia piece if the music is presented over headphones.

Multimedia installation

The following idea is an extravagant description of the author's vision of potential use of the previously discussed acoustic phenomena in a multimedia situation.

'The Ride' is a multimedia installation that emulates a boat journey. From the outside it looks like a photo booth, but once a person is inside, the container is completely sealed. The container has undergone acoustic treatments to try and isolate the sound within. Inside there is a seat for one participant, who has to be strapped in for the ride. On the floor there is a huge sub-bass speaker with a very low frequency range. It's capable of producing infrasound as low as 1Hz. In front of the seat is a large screen, and within reach there are a pair of high quality headphones also with a very low frequency range. Once the user is strapped in and the headphones are on, he/she must press a large red button and the ride begins.

An onscreen simulator takes the person through a variety of environments. It starts off nicely going through the Amazon River - birds are singing, fish are jumping and steam is rising from the water. Because the water was recorded with Holophonic equipment it can be heard from down below and travelling past the person. A light soundtrack is playing on the headphones, congas and bongos, and a faint chanting can also be heard. Binaural beats in the alpha range are embedded in the music, making sure the person is relaxed. This continues for a couple of minutes. Then in the space of 10 seconds, the sun goes down, the screen turns dark, the music stops playing. Barely visible bats can be seen flying around just ahead. As the boat gets closer to the bats, they can clearly be heard

flying from left to right. Real bats flying around have been recorded with holophonic technology so their closeness is terrifyingly real.

Just as the bats disappear, a distant drumming can be heard and the water in the river turns red. The drumming gets louder. Big thumps of a bass drum play through the sub woofer and the headphones. At the same time, an infrasonic noise of 17Hz is being played, the gain is slowly increasing. The boat enters caves and caverns, which depict the traditional view of hell; there are fires everywhere. There are creepy voices and wails in the headphones but they sound like they are all around the user, and flying very close to his/her face. The infrasound makes the user even more scared. It instils feelings of fear and sends chills down the spine. The person may even see little creatures within the fires that aren't actually there as their eyeballs oscillate with the power of the infrasound. This would certainly be a more powerful experience than an average Ghost Train ride and it could all be achieved with images and sound.

There are endless possibilities for creating intense multimedia experiences by using a combination of these acoustic phenomena, and new recording techniques. A similar set up could make computer scary games and films terrifyingly real.

CHAPTER 6

CONCLUSION

This thesis has thoroughly investigated the effects that certain acoustic phenomena, such as binaural beats and infrasound, can have on people. All possible sources were examined from the Neolithic era, through the age of sound in cinema, to the use of infrasound, acoustic weapons and the discovery of entrainment.

This thesis illustrated several instances where acoustic phenomena have been used by artists such as Magnetize, Boards of Canada, The Anti-Group Conspiracy, The Soundless Music Project, Marc Bain, Throbbing Gristle and Pan Sonic and went on to suggest further applications in detail.

With regards to binaural beats and entrainment, they have definitely changed some people's lives. In his paper on binaural beats[23], Richard Kennerly describes how entrainment changed his lifelong struggle with a mild learning disability. There are hundreds of other cases containing anecdotal evidence of binaural beats helping people in similar ways, and even as a relaxant they are noticeably effective, though independent empirical evidence is lacking and more investigation is necessary to observe their effectiveness in multimedia. However, previous experiments while few; do indicate towards possible applications in E-Learning software. Binaural beats could also enhance more abstract forms of artistic art and multimedia by inducing the viewer into slightly hypnotic or meditative states of consciousness. Detailed examples of both of these applications were discussed in the previous chapter.

As discovered by research into acoustic weapons, some of the more intense effects of low frequency sound on a large scale still have potential for making musical concerts more intense and the same goes for large-scale noise art and films. Infrasound is the most powerful of all the acoustic phenomena discussed in this thesis and could be used across a broad range of applications as discussed in the previous chapter, such as films, computer

games, music and multimedia art. The ‘Soundless music’ project, the film ‘irreversible’ and Mark Bain’s work have already demonstrated its power.

While visual effects have been progressing rapidly, sound in cinema is once again at a standstill. These new technologies should be implemented more, yet we need to investigate at what level we should implement them. We don’t want people running screaming out of every horror film. Or do we?

Future developments for acoustic phenomena in multimedia

As indicated above, the levels of infrasound that would be advisable to use, need thorough investigation for use in the application of multimedia art and film. Experiments with test audiences would need to be carried out before unleashing it on the general public without much thought.

For further investigation into the usefulness of binaural beats in E-Learning software, experiments should be carried out with a large number of participants. I believe that previous experiments with binaural beats have been conducted with too few people. I recommend using E-Learning packages such as Electric Paper’s ECDL software, as the CDs also contain assessments, so tests with a control group and a test group should be very easy to assess.

It would be harder to assess the success of binaural beats in conjunction with artistic multimedia but only in evaluating subjective moods and psychological assessments. A simple application would be to embed binaural beats in a musical Flash animation. Again I recommend carrying out an experiment with larger control and test groups. A web site could easily facilitate such a large scale experiment.

Although these tests will further clarify the usefulness of binaural beats and infrasound it is apparent that overall, there is huge potential for acoustic phenomena in both artistic and practical applications of multimedia.

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Appendix A

Magnetize interview

Braine: How did you become interested in Binaural Beats?

Magnetize: I think it was through reading an interview with Phill Niblock in which he was talking about a record he made for Blast First where he was multi-tracking layers of trombone at particular non-matching octaves & cycles. He was saying that the effect of the clashing cycles caused particular responses in people, especially at high volumes. I thought this was interesting because he mentioned that the clashing cycles were like waves of pure distortion. He was coming at it from an angle of disorientation and confusion of the listener, not an academic nerdy frequency calculation angle, but it was the first time I had heard it conceptualised as 'Binaural Beats'.

When I looked into the concept further, I found it very interesting that altered states of consciousness were possible through brainwave entrainment using binaural beats - the beating or phasing of low frequency signals could cause a marked psychological response. It made sense to me that brain activity is because of your brainwaves and the idea of Resonant Entrainment is that your brainwaves would be made to resonate in a particular fashion by introducing oscillation at slightly different phases to each ear.

Braine: Why did you use binaural beats in your performance?

Magnetize: I had just made an LP called Biome for Rimbaud Records and some of the tracks had elements of binaural beating. I felt that it was best either to listen to them through headphones or at very loud volumes to get the phasing psychoacoustic effects. So, Lazybird seemed like the best opportunity to air these binaural tracks in a proper environment.

However, it wasn't really possible to recreate the Biome binaural tracks as they had been

recorded using a variety of different instruments over the space of 5 years, mostly in one live take. So, I decided that I would use the concept of brainwave entrainment through binaural beats and try to do an hour or so on-the-fly.

Braine: Have you experienced any affects personally either during a performance or at another time?

Magnetize: I would say yes, particularly in the area of time distortion but also with pure meditation. I find that the setting and listening environment needs to be right - either very loud or through headphones. I've found myself messing around with four oscillators with beating frequencies and cross panning and a hour or two passing like a few minutes. Also it can be very easy to fall asleep to!

Braine: I spoke to one person who said "It was like the music was going through the inside of my head." I was wondering if you used panning with the sounds too.

Magnetize: Yes, panning was a big part of the Lazybird performance. Four oscillators were used, all panned - oscillators one and three hard left, two and four hard right.

Braine: Roughly, what percentage was the volume of the binaural beats compared to the other sounds in your music?

Magnetize: for the Ladybird gig, it's hard to say really, probably less than half at a guess. The tracks had a 'binaural' outset but were then manipulated into whatever came into my head at the time!

Braine: What software did you use to create the binaural beats?

Magnetize: No software was used for sound creation. I'm tired of computer-based products, and I much prefer working on real hardware. For the Lazybird performance I used a DSI Evolver which is an analog/digital hybrid synth that contains a 16x4 sequencer, four oscillators (two VCO, two DCO), four LFOs, three Envelopes, VCFs and VCAs and a myriad of routing possibilities, three-section delay unit and distortion. Linkage between tracks was done using sample manipulation on a Korg ESX1.

Braine: Did you set up the venue in any special way to increase the effects i.e. speaker positioning?

Magnetize: Ideally I would have liked a quadraphonic setup with each oscillator having its own output and the speakers setup in the four corners of the room. However there were a few practical problems with that - you'd need the audience to sit dead centre for that to properly work and the room was too small for that and they only had a stereo setup. So we just used the main stereo pair that sit above the stage.

Braine: Did any members of the audience tell you that they experienced any of the effects associated with binaural beats and if so what were those effects?

Magnetize: No, no one mentioned anything in that regard.

Braine: Did those audience members have a prior knowledge that you were going to use binaural beats and did they know the effect that they were supposed to have?

Magnetize: It was fully mentioned in the blurb for the gig.

Braine: Did you get any feedback about binaural beats from the recording of the night?

Magnetize: No.

Appendix B

Interview with Richard Lord of the National Physical Laboratory

Braine: The infrasound generator looks very low tech. Is this something an amateur could have a go at or are there important technical specifications that need to be taken into account?

Lord: You're right it is very low-tech and in fact was designed with a budget in mind. Our main criteria was that the infrasound 'generator' should be portable, cost effective, visually exciting and of course had to produce some infrasound. We selected the pipe design because the team had asked for a single frequency on the cusp of infrasound (about 17 Hz), and since the pipe is a resonant system we knew we could tune it by its length.

Braine: Exactly how was the sound produced? Was the pipe itself oscillated somehow? Was the loudspeaker used to amplify the sound from the pipe?

The sound was produced by a large diameter speaker driving the air in the pipe at its resonance frequency.

Assuming that the pipe acted as a pipe open at one end and closed by the loudspeaker, the fundamental frequency is then given by f = c/(4L), where c is the speed of sound (343 ms-1) and L is the effective length (in metres).

Our pipe extends 4.8 m from the speaker to the open end. An 'end correction' is applied for open ended pipes, which is 0.61*radius, making the effective length of the pipe (L) 4.9 m. The fundamental is 17.5 Hz which is the frequency we used. If you need a lower frequency, you need a longer pipe.

We had a shorter section of pipe on the back of the speaker (2.4 m long, also open ended) in the vague idea that the rear radiated sound would stimulate the fundamental frequency of this shorter section - which would be 35 Hz, the first harmonic of our infrasound. The idea being that this would be out of phase and perhaps help to cancel the first harmonic. However, we found that since we drove the pipe at 17.5 Hz, the first harmonic was already 50-60 dB down from our fundamental and the short section of pipe wasn't necessary. The pipe worked just as well without it - but became less visually exciting - so the shorter section stayed, and gives us the opportunity to lower the frequency, by moving the position of the speaker - if required.

The pipe that we used was a lightweight drainage/sewage! pipe, smooth on the inside, corrugated on the out. It's in three sections, so that we can dismantle and transport it fairly easily. It's 32 cm in diameter, and the 30 cm loudspeaker that we used is housed in one of the connection hubs. The speaker is made by Peerless (Danish company) and is one of their Xtra Long Stroke drivers (308 XLS SWR 51 146 NX ALP 4L subwoofer). The 'Long Stroke' means that the cone is capable of large displacements, without hitting a physical limit, and therefore large amplitudes can be produced. At low frequency the speaker was effectively working like a piston.

Braine: Was it hard to make the pipe resonate at 17Hz? Did you experiment with lower frequencies?

Lord: By driving the pipe at its resonant fundamental frequency (ie with a function generator producing 17.5Hz sine waves), we were able to produce
fairly high levels of infrasound 86-100 dB SPL, but this was strongly dependent upon location within the auditorium.

We have produced lower frequencies here in the lab, by connecting further sections of pipe to the system.

Braine: I've tried generating infrasound with pure tones on computer software

(soundforge) but haven't noticed the slightest effect personally. Do you think it's important to generate infrasound
naturally? Could a computer generated sound have the same effect?

Lord: It may be that you are limited by your sound reproduction system. The sound card in the computer, the amplifier and the speakers must all be able to reproduce the low frequencies. Otherwise there is no reason why you can't synthesize a low-frequency signal. To notice 'effects' a sufficient level is required. This is frequency dependent.

Braine: Do you think the effects of infrasound would be the same when experienced over headphones or would they have to be very expensive headphones with a low frequency range?

Lord: You would have to be able to reproduce the low frequencies from the headphones.

Braine: Is the loudness of infrasound very important to produce noticeable effects in humans? Do you need special microphones to record it and special speakers to re-produce it? It seems hard to judge the loudness of a sound when you can't actually hear it.

Lord: Loudness is related to the human response to sound. It's important to realise that loudness is frequency dependent. Contrary to its usual description, infrasound is audible. The sensitivity of the human ear decreases with frequency, and at 17.5 Hz, about 90 dB SPL is required to be able to detect the infrasound. A 20 Hz tone requires from 85 to 90 dB SPL to be audible, 10 Hz about 100 dB SPL and 2 Hz needs over 120 dB SPL.

We use measurement microphones (typically Bruel and Kjaer) to detect the low-frequency sound. Being a calibration laboratory we have the advantage of being able to characterise our devices at low frequencies.

Braine: Did you or your team experience any strange effects while working with infrasound?

Lord: Yes. Typically fatigue type effects.

During our concert, we monitored the acoustic level from 10Hz - 20 kHz, and set a limit on 90 dB exposure for the infrasound.

Braine: Of other elements of sound you work with at the NPL, ultrasound for example, have you noticed any strange effects it can have on people as comparable to infrasound?

Lord: We don't currently have any psycho-acoustic projects, but you will find that infrasound is not really that special. Just think of the annoyance caused by noise in the audio frequency range, or the emotions that can be induced by music.

Braine: Had you worked with infrasound at the National Physical Laboratory before this experiment?

Lord: The NPL does have a history of working with low-frequency sound having conducted experiments into detection thresholds.

Braine: Did you carry out any research on infrasound at the laboratory in preparation for the soundless music project or was the theory based mostly on previous research?

Lord: The theory was based on previous research.

Braine: The results are mainly psychological. Did anyone experience physiological effects such as visual distortion?

The sound pressure levels used were not high enough to create this type of effect which has been reported at very high levels.

Braine: There aren't many details online about the effects experienced by the 22%. Are the exact results of the questionnaires available?

Lord: For the psychologists report, please see:
http://www.spacedog.biz/infrasonic/infrasonicResults.htm#results