Effects of Acute and Chronic Noise Exposure on Cochlear Function and Hearing in Dogs

Rebecca Elisabeth Venn

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Institute of Biodiversity, Animal Health and Comparative Medicine

College of Medical, Veterinary and Life Sciences

University of Glasgow

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Chapter 1: Physiology of Hearing and Mechanisms of Hearing Loss in Dogs

This review will cover the basic anatomy and physiology of the ear and hearing. The main mechanisms of hearing loss will be described, and the behavioural impact of hearing damage on dogs and the methods of detecting it will be discussed.

1. Basic Anatomy of the Ear

The mammalian ear comprises three main areas; the external ear, the middle ear and the inner ear (Figure 1). The external ear is the visible appendage and the canal which leads to the tympanic membrane (ear drum); the middle ear is the air filled cavity behind the tympanic membrane, and the inner ear comprises the structures which transmit sound waves to nerves communicating the information to the brain.

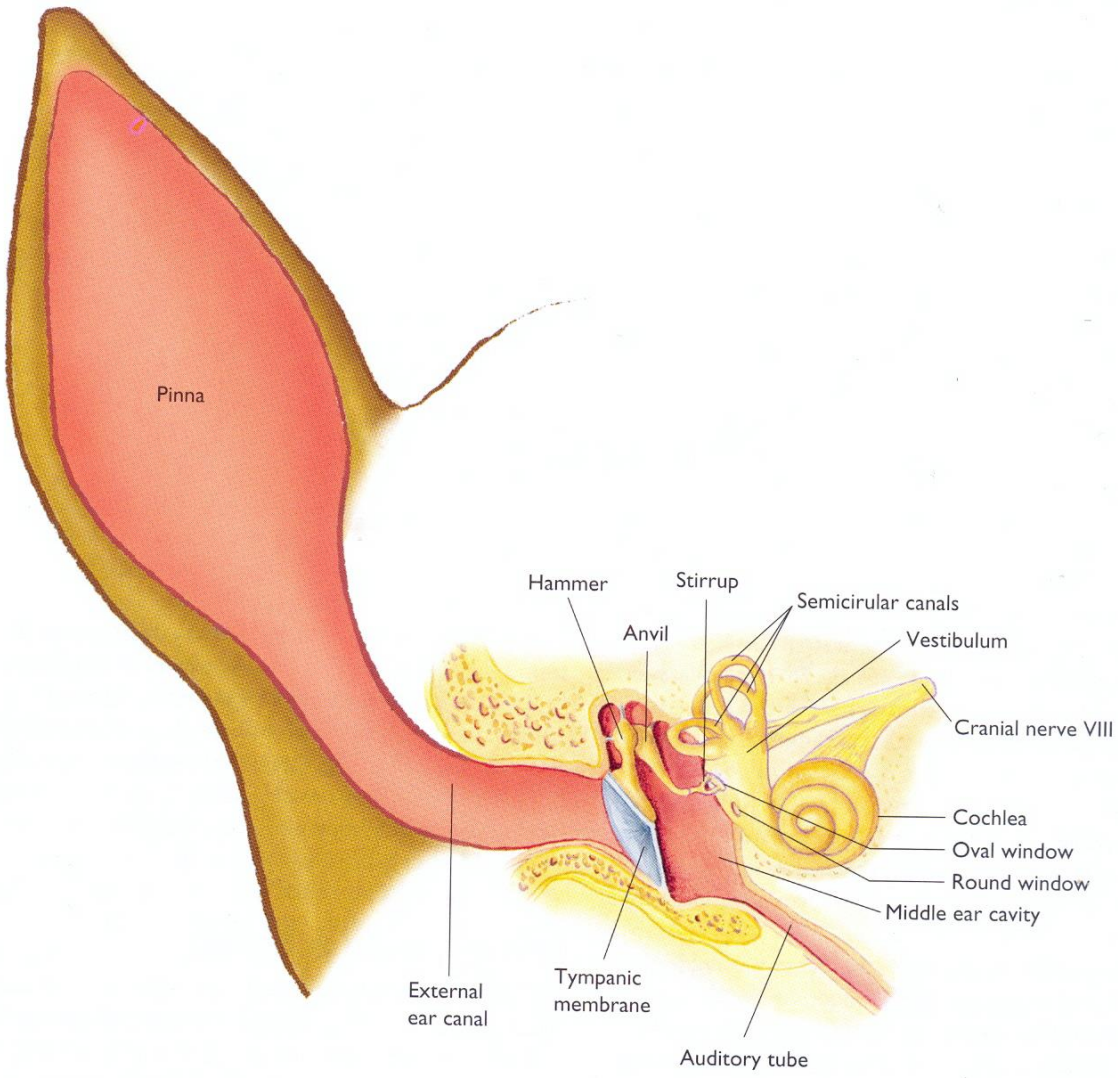

Figure 1: Simplified diagram of the structure of the outer ear, the middle ear, and the inner ear of dogs. From Physiology of Domestic Animals, Sjaastad, Hove & Sand, 2003.

1.1 Outer Ear

The outer ear is the external visible appendage, known as the pinna or auricle, and the external ear canal which leads to the tympanic membrane (ear drum), as seen in Figure 1. Amongst different breeds of dog the pinna can have a very different appearance, from the long floppy ears of spaniels, to the big triangular ears of German Shepherd dogs. Despite extrinsic differences, the pinna of all ears function like a funnel, collecting sound waves and directing them into the ear canal. Many species, including dogs, are able to orientate the pinna towards sound, increasing the sensitivity of their hearing. The external ear canal is a tube which transmits waves of sound to the ear drum. Whilst in humans the external ear canal is straight, in dogs, it has a vertical followed by a horizontal portion, forming an L-shape to the tympanic membrane.

1.2 Middle Ear

The middle ear is the air filled cavity behind the tympanic membrane, which contains three little bones, the auditory ossicles, and also the opening to the eustacian tube (Figure 1). The auditory ossicles are individually named the malleus (hammer), the incus (anvil) and the stapes (stirrup). The auditory ossicles lie in a chain from the inner edge of the tympanic membrane to the oval window, one of the two membranes connecting the middle ear to the inner ear (the second being the round window). The malleus and the stapes are also connected to two small skeletal muscles; the tensor tympani and the stapedius muscles. These muscles protect the inner ear by contracting upon high-intensity noise and decreasing the energy transfer. The eustacian tube connects the middle ear to the pharynx and is responsible for keeping the pressure in the middle ear in equilibrium with the external atmosphere (Sjaastad et al., 2003).

1.3 Inner Ear

The inner ear is made up of complex fluid-filled structures known as the semi-circular canals, the vestibulum and the cochlea. The semi-circular canals and vestibulum are responsible for the sense of balance, while the cochlea is responsible for hearing.

The mammalian cochlea is a coiled structure, often compared to the shell of a snail, and is responsible for converting the vibrations created by sound to action potentials in sensory neurones connecting the brain. The coil is formed by three parallel fluid-filled canals; the scala tympani, the scala vestibuli and the scala media (Figure 2). The scala tympani and scala vestibuli are actually one long tube, which bends back on itself at the apical end of the cochlea, and the scala media lies between them. The scala tympani and scala vestibuli are filled with perilymph, whilst the scala media is filled by endolymph. The scala media is separated from the scala vestibuli by the Reissner's membrane, and from the scala tympai by the basilar membrane. The third wall of the scala media is formed by the stria vascularis, which produces endolymph. On the scala media side of the basilar membrane, the organ of Corti is situated (see Figure 2), which is lined by between four and six rows of sensory hair cells and surrounded by endolymph. There are two types of hair cells on the organ of Corti: three rows of outer hair cells and one row of inner hair cells, all overlain by the tectorial membrane. Little stereocilia project from the top of the hair cells, which lie close to the tectorial membrane (Randall et al., 2002; Sjaastad et al., 2003).

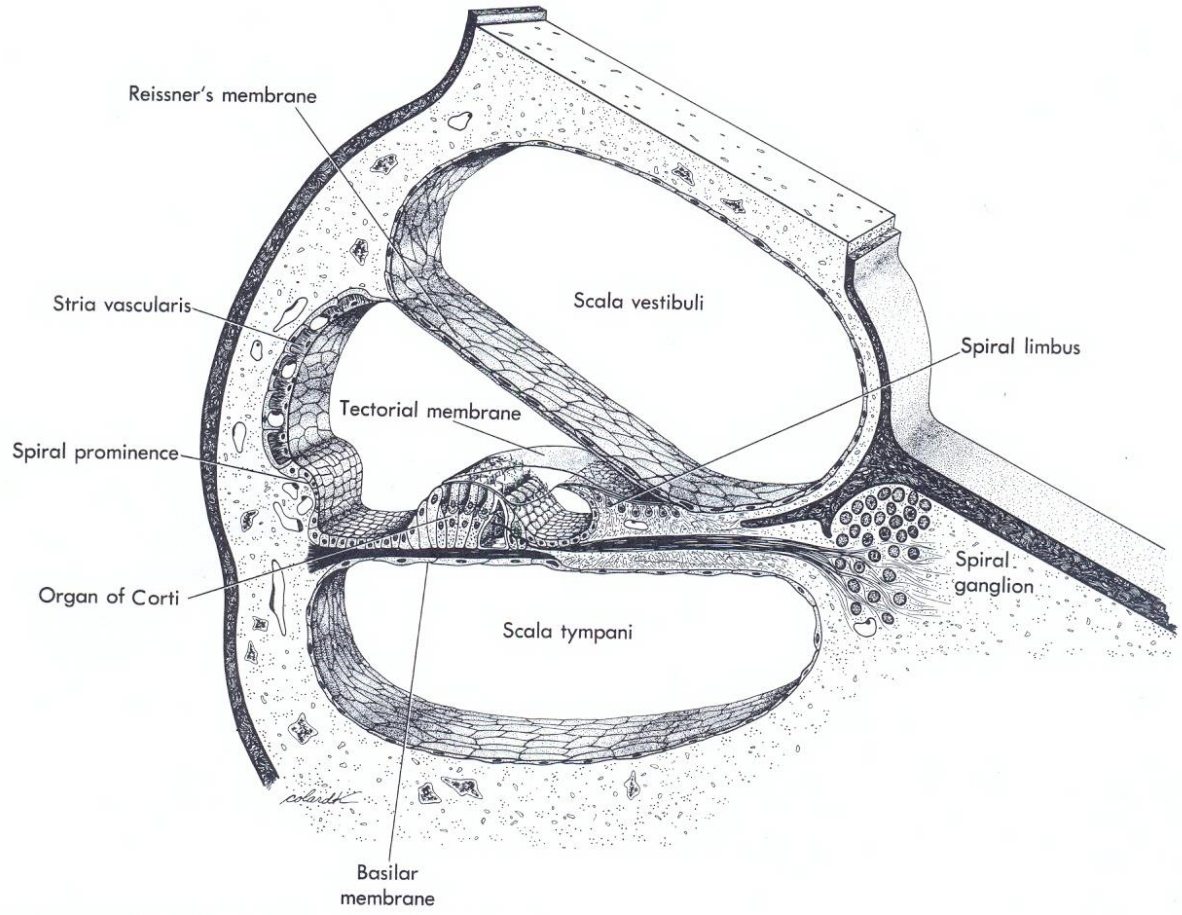

Figure 2: Diagram showing a cross-section through one of the turns of the cochlea. The Scala media is situated between the Scala vestibuli and Scala tympani. From Bloom W, Fawcett DW: A Textbook of Histology, 10th ed. Philadelphia: WB Saunders, 1975).

1.4 The Sense of Balance

Two otolith organs (the utricle and saccule) in the vestibulum and the three semi-circular canals are known as the equilibrium organs of the inner ear. These equilibrium organs provide information to the brain, via cranial nerve VIII, essential for balance, coordination and posture. The semi-circular canals detect angular acceleration, providing information relating to movements of the head, whilst the otolith organs detect linear acceleration and allow us to distinguish up from down (Sjaastad et al., 2003).

The semi-circular canals lie on three different planes, perpendicular to each other. The semi-circular canals contain endolymph, and specific regions of the walls are lined by sensory hair cells, which project into a gel known as cupula. When the head turns, the

cupula moves, causing bending of the sensory hair cells, which in turn stimulates the underlying sensory epithelium. The combination of information from the movements of hair cells in each of the three semi-circular canals allows the brain to identify the specific rotation of the head (Sjaastad et al., 2003).

The otolith organs are formed by hair cells projecting into a gelatinous mass containing calcium carbonate crystals. The utricle is lies horizontally and the saccule is located vertically, on a lateral wall. When the head is tilted (linear acceleration), the semi-circular canals all move to the same extent, consequently the sensory hair cells are not stimulated. However the gelatinous mass of the otolith organs will move and stimulate the underlying sensory epithelium, allowing the brain to determine which way the head is tilted (Sjaastad et al., 2003).

2. Physiology of Hearing

Whilst anatomically, the human and dog external ear appear to be very different, physiologically, the mechanism of hearing is the same in both species Sound causes a pressure difference between the external ear and middle ear, which results in vibration of the tympanic membrane. When the tympanic membrane vibrates, this energy is transferred to the auditory ossicles and then on to the oval window and the cochlea in the inner ear. When the third auditory ossicle (the stapes) vibrates, it pushes into the oval window, which causes an increase in pressure in the cochlea perilymph. This increased pressure forces the basilar and Reissner's membranes to displace and the round window is also distended. As the basilar membrane moves, the stereocilia push up against the tectorial membrane and the sensory hair cells are moved. The stereocilia contain stretch-sensitive ion channels at their tip. When the stereocilia bend in a certain direction, little filaments tauten, causing the ion channels to open and allow an influx of potassium ions into the hair

cells. This causes depolarisation of the hair cell which in turn opens voltage-gated calcium channels and causes an influx of calcium ions. This influx of calcium causes exocytosis of an excitatory neurotransmitter (glutamate or aspartate), which stimulates the adjacent sensory neurones of the auditory (cochlear) nerve (cranial nerve VIII) (Hill et al., 2008; Randall et al., 2002; Sjaastad et al., 2003). The stimulated action potential travels to the cochlear nuclei in the medulla oblongata (collections of neurons in the brainstem), which then carries the information via the lateral lemniscus (a tract of axons in the brainstem) and the inferior colliculi (in the midbrain) to the medial geniculate body (part of the auditory thalamus). Finally, the information is passed into the auditory cortex in the cerebrum, where the conscious perception of sound occurs (Cunningham, 2002). Not all cochlear afferent fibres are stimulated in response to all sounds. The afferent fibres which discharge depend on the frequency of the sound. Different frequencies of sound affect the degree of displacement at different areas along the basilar membrane, in turn stimulating different sensory neurones in the organ of Corti and allowing different frequencies of sound to be distinguished (Berne et al., 2004). High frequency sounds stimulate vibrations along the basilar membrane close to the oval window, whereas lower frequency sounds cause vibrations of the basilar membrane further away from the oval window.

3. Hearing Range of Dogs

Different animals are sensitive to different frequency ranges of sound. The frequency of a sound is the variation in pressure over time, and it determines the pitch of the sound. Young humans can perceive frequencies of approximately 20-20,000 Hz. Dogs in comparison, are able to perceive frequencies from approximately 67 Hz to 45,000 Hz (Fay, 1988). In general, larger mammals have a better sensitivity for low frequency sounds and small mammals have a better sensitivity for high frequency sounds. For example,

elephants are able to hear sounds below 20Hz (known as infrasound), allowing them to communicate across long distances; whilst some bats can hear frequencies above 100,000Hz, allowing them to echolocate (Sjaastad et al., 2003).

The reason for variation in hearing range between mammals is due to anatomical differences in the outer, middle and inner ear. Firstly, the outer ear (pinna) is more mobile in some species than others (e.g. dog versus human), allowing the animal to adjust the direction of the ear in relation to the source of the sound, in order to optimise transmission of the sound to the eardrum (Heffner and Heffner, 2007). Some domestic dogs have evolved with a reduced sense of hearing compared to their wolf ancestors due to a dropped ear shape (Clutton-Brock, 1995), which covers the opening into the external ear canal and reduces sound transmission to the tympanic membrane. Selective breeding is also accountable for the different shapes of the pinna between different dog breeds (Clutton-Brock, 1995). Secondly, the size of the middle ear may affect the hearing range of an animal. It has been found that the hearing sensitivity of kangaroo rats depends on the size of the middle ear (Webster, 1962). Finally in the inner ear, the number of spiral turns the cochlear forms has been found to positively correlate with the octave range of frequencies which ground dwelling mammals can hear (the human cochlea has 2.75 turns, whilst the dog has 3.25), and the basilar membrane length relates to upper and lower hearing limits (the human basilar membrane is between 33.5 and 35mm, whilst the dogs' is 22-23mm long) (West, 1985).

4. Noise Level

The loudness of a sound is described using units called decibels (dB). The decibel scale is a logarithmic scale; for every increase in 10dB SPL (sound pressure level), the intensity of a sound increase by a factor of ten. For example, a sound of 60dB is ten times louder than

a sound of 50dB. A normal human conversation is approximately 60dB SPL, the volume of busy traffic is around 90dB SPL (Tripathy, 2011), and sustained noise above this level is considered to be damaging to the ear and results in hearing loss (Thiery and Meyer-Bisch, 1988). A human will experience pain when exposed to volumes from 130dB SPL upwards (Tripathy, 2011).

Noise levels are most often measured as LAeq, the equivalent continuous level, which is essentially the average sound level over a given period of time. Some sound level meters are capable of calculating the LAeq automatically, by taking many regular measurements of the sound level over a period of time and calculating the average. However, this is not a simple arithmetic average, since decibel measurements are on a logarithmic scale. To calculate the LAeq manually (as is required when using a very simple sound level meter), the sound levels must be converted from decibels to 'real' numbers, added up, then divided by the number of measurements, and the result converted back to decibels (website 1). One issue of using the LAeq alone to assess noise levels is that, since it is an average, many quieter sounds could produce the same LAeq as just one or two very loud sounds. Consequently, LAeq measurements alone do not give an indication of the range of volumes of sound being measured. The LAmax is the highest level measured by the sound level meter over a given period of time.

Sound measurements recorded by most sound level meters can either be fast or slow time weighted. The fast weighting shows quick fluctuations in the sound level, whereas the slow weighting dampens the readings, making fluctuations slower and easier to read. Fast weightings have a 125 millisecond averaging time and slow weightings have a 1 second averaging time. (website 2).

5. Hearing Loss

There are three main classifications of hearing loss: Conductive, Sensorineural and Central (Pocock and Richards, 2004). Conductive hearing loss is caused by a defect in the outer or middle ear preventing sound transmission from the source to the cochlea, for example blockage of the external ear canal by cerumen (wax), or a middle ear infection. Sensorineural hearing loss is caused by lesions inhibiting transmission in the inner ear, for example loss of sensory hair cells, auditory nerve damage, or vascular damage (Isaacson and Vora, 2003). Causes of sensorineural deafness include ototoxic substances (e.g. aminoglycoside antibiotics); presbycusis (age-related hearing loss); congenital hereditary factors (Strain, 2004); and high-intensity noise. There is no treatment for sensorineural hearing loss as the death of hair cells is permanent (Cox, 2002). Central deafness is caused by interruption of the auditory pathways in the brain.

5.1 Congenital Sensorineural Deafness

In dogs, congenital sensorineural deafness, also known as pigment-associated deafness, is related to the white coat phenotype (e.g. Dalmatians, bull terriers) and merle colouring (e.g. border collies) (Platt et al., 2006). At least 80 breeds of dogs are associated with congenital deafness (Strain, 2004). The cause of pigment-associated deafness is not fully understood (Strain, 2004), however the stronger the expression of the white producing genes, the higher the incidence of deafness. Blue eyes also indicate a strong expression of these genes, however not all dogs with blue eyes will be deaf (Strain, 2004). Animals with pigment-associated deafness have an absence of melanocytes in the stria vascularis, which are thought to be related to cochlear function in this location (Steel and Barkway, 1989). It has also been found that deaf Dalmatians have a loss of outer hair cells from a young age,

which have instead been replaced by supporting cells; a likely cause of the deafness (Sampaio et al., 2010).

The mode of inheritance of congenital sensorineural deafness is complex and has not been fully established in most breeds (Platt et al., 2006). The offspring of a deaf dog will not necessarily be deaf too. Despite this, dogs found to have congenital sensorineural deafness should be removed from the breeding pool to decrease the incidence of this inherited form of deafness (Wood and Lakhani, 1997).

5.2Noise-Induced Hearing Loss

Damage to sensory hair cells due to excessive noise is known as Noise-Induced Hearing Loss and may be temporary or permanent, depending on the intensity and duration of exposure. Different individuals vary in their susceptibility to noise-induced hearing loss and those most at risk cannot easily be predicted (Radomskij et al., 2002). Over-stimulation of the hair cells causes a massive production of reactive oxygen species, which causes oxidative cell death (Yamane et al., 1995). As a result, there is a decrease in stimulation of sensory neurones connecting the auditory nerve. Hair cells closest to the round window on the basilar membrane are the most vulnerable to over-stimulation and death. The cells closest to the round window perceive high frequency sounds, and cells furthest away perceive low frequency sounds. Consequently, the first hearing loss due to excessive noise will theoretically be a reduction in sensitivity to high frequencies (Gelfand, 2009).

Transient evoked otoacoustic emissions testing (TEAOE) (a type of hearing test described below, section 6.2.4) has been used in cats to assess the effects of exposure to 2kHz pure tone at 125dB SPL and 105dB SPL for 30 minutes (Iwasaki et al., 1998). It was found that the tone burst-evoked TEOAEs waveforms could not be detected immediately post noise

exposure in any of the cats. In the cats exposed to 105dB SPL, the recovery of the TEOAE to the original threshold took an average of 107.5 minutes. In the cats exposed to 125dB SPL, the TEOAE responses could still not be detected at a stimulus level of 60DB SPL a week after the noise exposure. These results indicate cochlear dysfunction as a result of excessive noise stimulation.

To determine the effects of noise at different intensities and for varying times of exposure, an experiment (Spoendlin and Brun, 1973) was performed on 110 guinea pigs, which were exposed to noise of between 110 and 140dB for periods of time between 30 seconds and 1 week. The animals were then sacrificed and dissected to look at the effect the noise had on their cochlea. After a long exposure of noise levels between 110 and 120dB scattered degeneration of outer hair cells is seen, due to metabolic damage. At noise levels between 120 and 130dB hair cells undergo mechanical as well as metabolic damage, even for short periods of exposure time (5 minutes). Mechanical damage is usually irreversible, whereas metabolic damage (more common at lower intensities) is partly reversible. However, the longer the animal is exposed to levels of noise between 110 and 130dB, the worse the damage done. At the lower noise levels tested in this experiment, exposure time is an extremely important factor regarding the degree of damage, whereas at higher intensities, exposure time almost becomes irrelevant, as the damage is done almost instantly.

5.3 Impact of Hearing Loss in Dogs

Dogs with unilateral deafness may have difficulty localising sounds and they may not awaken in response to noise if they are asleep with the hearing ear down (Strain, 1996; Strain, 1999). Dogs with bilateral deafness can be more difficult to train and require the use of hand signals; consequently these dogs may be less desirable and difficult to home.

Dogs with unilateral or bilateral deafness are at higher risk of traffic accidents, due to not hearing cars, and so owners need to be extra cautious (Strain, 1996; Strain, 1999). These dogs may potentially also pose a public safety risk; it is often suggested that deaf dogs may be develop a nervous and aggressive nature, due to an increased likelihood of being startled (Cox, 2002; Strain, 1996; Strain, 1999), but no studies have actually proven this.

A study was conducted to determine whether there is a link between nervousness in Pointer dogs and hearing loss/deafness. It was observed that a group of Pointer dogs which had been selectively bred for increased nervousness, showed signs of a hearing deficit. All of the dogs were tested for their "degree" of nervousness, and their hearing ability was also tested (by brainstem auditory evoked response, BAER (see below, section 6.2.3), to determine a link. Twenty out of the 27 nervous dogs tested were found to be deaf, begging the question, is it a genetically linked but unrelated quality, or is the deafness causative of the nervousness (so they are inadvertently breeding for deafness)? Since the other 7 nervous dogs in the group were found to have hearing within a normal range but no difference in their degree of nervousness, it was concluded that the deafness was *not* causative of the nervousness in this case, otherwise it might be expected that all of the nervous dogs would be deaf (Klein et al., 1988). The results of this study may suggest that genetically deaf dogs do not necessarily all develop a nervous disposition. Genetically deaf dogs, which have never experienced hearing, may naturally adapt in other ways, without any fear, for not knowing what they are missing. Perhaps if a study was to be conducted on dogs which were born hearing but had lost their hearing (due to old age or ear disease etc.), it might be found that deafness is causative of nervousness, or even aggression, in some cases.

6. Testing Auditory Function in Dogs

Testing auditory function in dogs is important for screening breeds which are affected by congenital deafness; testing working dogs (e.g. hearing dogs) and service dogs, in which impeccable hearing is vital; detecting presbycusis (age related hearing loss), ear pathology and noise-induced hearing loss (Scheifele and Clark, 2012).

Broadly speaking, there are two categories of hearing screening used in dogs (and humans). The first are subjective tests, which involve observing the individual being tested, and looking for behavioural responses to sounds. Alternatively, there are objective tests, which are unbiased and use special equipment to test auditory function, which should avoid error by subjective opinion.

6.1 Behaviour Testing for Hearing Ability

The most common subjective method of assessing hearing in humans is called Audiometry, which simply involves playing tones of different frequency (dB) and intensity (Hz) to an individual, and they are instructed to raise a hand or push a button to indicate to the assessor when they hear a sound. This method of hearing assessment has also proven successful for use in dogs, by looking for behavioural signals when the dog hears a sound. For example, in one study (Van Der Velden and Rijkse, 1976) dogs were trained by operant conditioning to learn that when they heard a sound, they could open a little hatch with their nose to access a treat (if there was no sound, the hatch did not open). Once the dog had learned the rule, sounds of varying frequency and intensity were played, and if the dog reached for a treat it confirmed that the sound was heard. The problem with this method of hearing assessment is that it is time consuming (as dogs need to be trained before the assessment can be successfully performed) and this makes it unsuitable in most instances.

An alternative method of behavioural audiometry which has been found to be successful in dogs (Van Der Velden and Rijkse, 1976) is to heat up the test room so that the dog starts panting and then play a sound. If the dog hears the sound, it will suddenly stop panting for a moment. This is a simple, fast test and is fairly reliable since this is a usual response of dogs and can be easily observed.

A simpler behavioural hearing test for dogs involves making a sudden noise (e.g. hand clapping) outside the dog's visual field and looking for a response, such as a head turn (Cox, 2002; Strain, 1996; Strain, 1999). The advantage of a behavioural hearing test for dogs is that it allows a quick and cheap initial assessment of hearing ability, which can then be further investigated by more reliable methods, if necessary. In general, behavioural hearing tests are subjective tests and may not be reliable; the dog could be responding to some other stimuli despite not hearing the noise, and on the other hand it could become habituated and hence unresponsive to the noise and may appear deaf to the assessor.

The other disadvantage of behaviour testing for hearing loss is that it does not localise the source of the problem if a hearing deficit is suspected, which means that a diagnosis and treatment plan cannot be established (Cox, 2002). Finally, behavioural methods of hearing testing cannot be used to reliably detect unilateral hearing loss (Scheifele and Clark, 2012).

6.2 Objective Tests of Auditory Function

Objective methods of assessing auditory function include Tympanometry, Acoustic Reflex Testing, Brainstem Auditory Evoked Response (BAER) testing, and Otoacoustic Emissions (OAE) testing. All of these are techniques which have been developed for testing the auditory function of humans, but have also been adapted for use in dogs.

6.2.1 Tympanometry

Tympanometry is used to measure compliance of the tympanic membrane (how mobile it is). It provides an indirect measure of air pressure in the middle ear and also an approximate measure of the volume of the external ear canal. The test is performed by inserting a probe into the external ear canal and playing a tone of 226Hz. As the external canal pressure is varied, the compliance of the tympanic membrane is measured. Tympanometry is used to diagnose middle ear infections (Bredfeldt, 1991).

6.2.2 Acoustic Reflex Testing

The acoustic reflex is an involuntary contraction of the middle ear muscles, which occurs in normal ears upon noise stimulation. The function of the acoustic reflex is to decrease the compliance of the tympanic membrane and attenuate high intensity sounds, thus protecting the inner ear (Cole et al., 2000). The presence of an acoustic reflex represents in-tact nerves and muscles involved in this pathway, and testing for it can be used for detection acoustic nerve tumours (Anderson et al., 1969; Jerger et al., 1974).

6.2.3 Brainstem Auditory Evoked Response Testing

The Brainstem Auditory Evoked Response (BAER) test is probably the most commonly used method of assessing auditory function in companion animals. BAERs are electrical potentials which are measured in cranial nerve VIII and the brain stem, in response to stimulating the cochlea; either a noise delivered to the ear via earphones, or a direct vibration of the mastoid bone. The electrical potentials are measured in dogs using subcutaneous needle electrodes placed on the head and in front of the ears. The measurements are converted into a continuous trace, with typically between four and six characteristic waves produced with normal hearing (Wilson and Mills, 2005). The BAER is safe and fairly non-invasive (but does require superficial needle insertion in dogs).

However, the dog being tested often needs to be sedated to prevent excessive movement or the dog making noise, which could alter the results. Furthermore, the use of this test is restricted to certain clinics, due to its specialised nature and high cost of equipment (Strain, 1999). Importantly, the BAER does not directly test cochlear function and hence is not ideal for assessing noise-induced hearing loss.

6.2.4 Otoacoustic Emissions Testing

Otoacoustic Emissions (OAE) testing is a non-invasive method of detecting the function of the outer hair cells of the cochlear, making it a specific test for sensorineural deafness (Radomskij et al., 2002). For this reason, OAE testing is ideal for assessing cochlear damage as a consequence of noise exposure, i.e. noise-induced hearing loss. Ultimately, OAE testing is not a hearing test, but a test of cochlear integrity.

Otoacoustic emissions are low level sounds produced by the outer hair cells of the cochlea, and they can be measured using a sensitive microphone placed in the external ear canal; this is the basis of OAE testing. OAEs are produced by vibration of the hair cells when the basilar membrane moves due to noise stimulation (Kemp, 2002). Otoacoustic emissions can provide an early indication of cochlear dysfunction, before any audiometric change occurs in hearing thresholds (Desai et al., 1999). OAEs may be spontaneous (SOAE), occurring in absence of external stimuli, or evoked, occurring in response to acoustic stimuli. Evoked OAEs can be split into two categories: transient-evoked OAEs (TEOAE) and distortion-product OAEs (DPOAE) (Iwasaki et al., 1998). TEOAEs are emissions, between 1 and 4 kHz, produced by hair cells following stimulation by broadband clicks over a wide range of frequencies. By comparison, DPOAEs are produced following stimulation with simultaneous pairs of frequencies (Goncalves et al., 2012).

A probe, which contains a small speaker and a microphone and is connected to the OAE equipment and a computer (Figure 3), is placed in the external ear canal. The speaker repeatedly delivers a stimulus and the microphone records the emissions from the cochlear hair cells. Whilst it is theoretically possible to perform the OAE in non-sedated adult dogs, it is more easily performed in sedated or anaesthetised dogs (see Figure 4), to prevent excessive movement and displacement of the probe, or vocalisation from the dog (Goncalves et al., 2012). The positioning of the probe is very important and a good fit in the ear is required for a reliable test. The test is affected by ear wax blocking the ear canal so it is useful to clean the ears with a dry swab before inserting the probe. The OAE test is also extremely sensitive to excessive external noise, which can affect the results; consequently a quiet environment, and a noise-reducing ear muff covering the test ear, are important in successfully performing an OAE test (Goncalves et al., 2012).

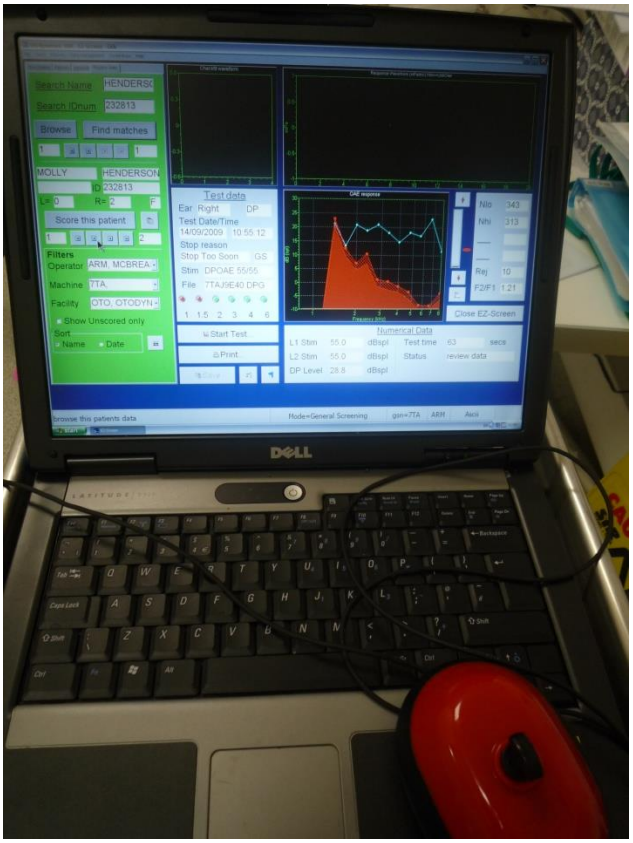

Figure 3: Computer showing Otoacoustic Emissions software output.

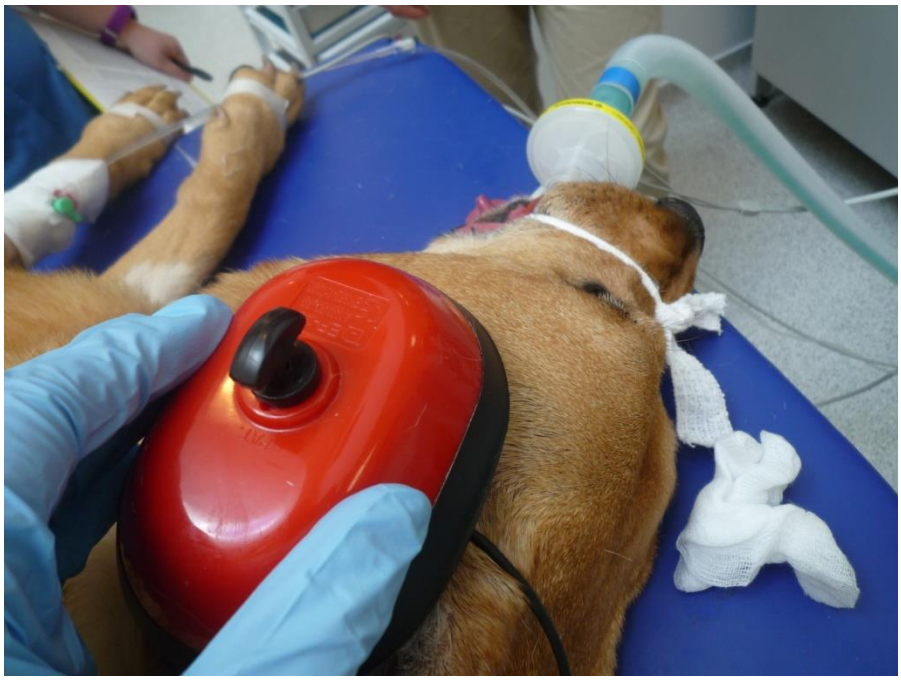

Figure 4: Anaesthetised dog having a DPOAE test performed. The probe is in the external ear canal, with the cable connecting to the otoacoustic emissions equipment, and the noise-reducing ear muff covers the test ear to exclude as much environmental noise as possible.

7. Project Aims

The aims of this project were to determine the effects of acute (MRI scanner noise) and chronic (dog kennel noise) exposure to loud noise on the cochlear function of dogs and whether there is a resultant welfare concern for these dogs.

MRI scanners are an example of an event where dogs are acutely exposed to potentially damaging levels of sound. The effect of exposure to MRI scanner noise on dogs' cochlear function has not been previously assessed, but with the increasing availability of this imaging technique in veterinary diagnostics, it is important to consider any adverse effects which it may generate.

Chronic cochlear damage may occur to dogs staying in kennels, as they are subjected to excessive noise levels for longer periods of time. The effect of kennel noise on the cochlear function of dogs has not been studied, however particularly in shelter kennels, dogs can be exposed to excessive noise to significant amounts of time, potentially resulting in noise-induced hearing loss.

The aims of this project were as follows:

1. To determine if acute exposure to noise (MRI scanning) has a detrimental effect on cochlear function (as measured by DPOAE) in dogs
2. To determine if varying levels of chronic exposure to a noisy kennel environment (rehoming shelter) has a detrimental effect on cochlear function (as measured by DPOAE) in dogs

Chapter 2: The Effects of Magnetic Resonance Imaging Noise on Cochlear Function in Dogs

Abstract

In specialised veterinary hospitals, Magnetic Resonance Imaging (MRI) scanners are used daily in diagnostics of dogs. MRI scanners omit high levels of acoustic noise, which is known to be damaging to the hearing of human patients without effective ear protection. However, the effects of the MRI noise levels on the cochlear function and hearing of dogs is often overlooked and in many clinics, dogs are not provided with ear protection for the duration of their scan. The aim of this study was to assess the effects of MRI acoustic noise on the cochlear function of dogs, by Distortion Product Otoacoustic Emissions (DPOAE) testing dogs immediately before and after they underwent an MRI scan. A group of control dogs undergoing a quiet procedure (but treated with the same range of anaesthetic drugs) were also tested. Post-MRI, the mean DPOAE of the dogs was reduced at all frequencies tested, significantly so at five (out of fourteen) frequencies, reflecting a reduction in cochlear function. Furthermore, at all frequencies tested, more than half of the ears exposed to MRI noise demonstrated a decrease in DPOAE. Without repeat DPOAE testing of the dogs some weeks after their MRI, it is unknown whether this effect is temporary and reversible, or permanent. Nevertheless, the results support a recommendation that all dogs undergoing an MRI scan are provided with ear protection as a precautionary measure.

1. Introduction

Magnetic Resonance Imaging (MRI) scanning is an increasingly popular, non-invasive diagnostic imaging tool used in veterinary patients, primarily for diagnostic purposes of detecting pathology in the brain and spinal cord (Dennis, 2003) and also for research. MRI scanners do not produce harmful radiation (as CT and radiography do) and are generally considered safe, however they produce noise levels, which vary in intensity depending on the MRI system used, but are usually between 65 and 95dB SPL (Kanal et al., 1990) and have peaks of between 120dB SPL and 131 dB SPL (Counter et al., 2000; Radomskij et al., 2002; Wagner et al., 2003), which has raised concerns of damage to cochlear function in humans (Radomskij et al., 2002) and noise-induced hearing loss (Brummett et al., 1988). See Appendix 1 for a description of how MRI scanners produce noise. In one study, up to 43 per cent of human patients going through an MRI scanner were found to have temporary threshold shifts in their hearing (Brummett et al., 1988). Although the hearing damage caused by MRI noise in humans appears to be temporary and reversible (Brummett et al., 1988), protective ear muffs/plugs are recommended to attenuate the noise exposure (Gangarosa et al., 1987). It has been confirmed that MRI scanners produce noise at levels which could be damaging to dogs' hearing (Lauer et al., 2012), however, to date, nobody has looked directly at the effect which the noise has on canine cochlear function. If MRI scanning was found to have a deleterious effect on cochlear function, and hence hearing in dogs, this could have serious implications; for example, working dogs such as hearing dogs depend on their hearing. Cochlear damage also raises welfare concerns in the safety of the dog and its owners; dogs with impaired hearing are more at risk (Luttgen, 1994) of getting run over (due to not hearing traffic) or lost (due to not hearing their owners call) and of being startled, which may make them more inclined to be

aggressive (Strain, 1996). Dogs with impaired hearing are often unwanted (Strain, 1996) as they may be more difficult to train. Hearing loss could also reduce their ability of dogs to hear vocal communication signals and localise sounds (Lauer et al., 2012). Finally, the high levels of acoustic noise produced by an MRI scanner could cause inner ear pain or discomfort and cause stress (Lauer et al., 2012). If MRI scanning is shown to damage cochlear function, it may be necessary to provide ear protection to dogs undergoing MRI scans, in the form of well-fitting ear plugs or muffs.

Noise induced hearing loss occurs as a result of oxidative death to sensory hair cells in the cochlea by overstimulation, due to excessive noise (Yamane et al., 1995). Hair cells detecting high frequency sounds are most vulnerable, so theoretically the first hearing loss will be a reduction in sensitivity to high frequencies (Sjaastad et al., 2003). Noise induced hearing loss has been observed in dogs which are kept in kennels and are exposed to a mean continuous noise of 100dB or more (Scheifele et al., 2012).

Brainstem Auditory Evoked Response (BAER) testing is the most popular method of evaluating auditory function in dogs and involves detecting nerve impulses in the brainstem in response to a click stimuli played into the animal's ear. Whilst the BAER test can detect deafness in a dog, it does not provide any specific information on the cause. Otoacoustic Emissions (OAE) testing is a more appropriate method of detecting noise induced hearing loss, as it specifically evaluates the integrity of the sensory hair cells of the cochlear (Rogers et al., 1995). Otoacoustic emissions are low level sounds produced by the outer hair cells of the cochlea, which may be evoked in response to noise stimulation. For this study, Distortion Product OAE (DPOAE) testing was used, as opposed to Transient Evoked OAE (TEOAE) testing, because DPOAEs have a wider useful frequency range than TEOAEs (Kemp, 2002). In DPOAE testing, a non-invasive

probe is placed in the external ear canal of the patient, which delivers simultaneous pairs of frequencies (denoted f_1 and f_2, where $f_2>f_1$) to the cochlear, evoking detectable emissions at a third frequency (most commonly $2f_1-f_2$), produced by the cochlear hair cells (Goncalves et al., 2012). F_1 and f_2 are kept at a fixed ratio, usually of 1.2:1 (where $f_2>f_1$) but the frequencies played are varied to test the integrity of different regions of the cochlea, as these detect different frequencies of sound.

1.1 Aims

The risk of cochlear damage due to MRI noise in dogs, which could possibly be mitigated by the use of ear protection, is a potential concern from a welfare perspective but as yet no assessment of this damage has been performed in dogs.

The aim was to investigate the effect of noise produced by the MRI scanner on the cochlear function of dogs, by comparing the results of DPOAE testing before and after they underwent a routine MRI investigation. A control population of dogs, undergoing anaesthesia for quiet procedures and not exposed to MRI scanner noise, was also DPOAE tested at the beginning and end of anaesthesia, to control for any potential deleterious effects of anaesthetic drugs on cochlear function.

2. Materials and Methods

2.1 Animals

Ethical approval from University of Glasgow Veterinary School Clinical Research Ethics committee was obtained. Data was collected over a period of seven weeks, in the University of Glasgow Small Animal Hospital.

Dogs undergoing anaesthesia for an MRI scan (see photo: Figure 5) were potential candidates. MRI was performed using a 1.5 Tesla MR imaging system (Magnetom, Siemens). The MRI studies comprised a variety of sequences, but in all cases T1-weighted (360-870/10-15; range TR/TE) and T2-weighted (2160-5890/86-130; range TR/TE) sequences were performed. T1-weighted post-intravenous gadolinium injection (0.1mmol/kg of Gadopentetate Dimeglubine, Magnevist; Bayer HealthCare Pharmaceuticals) studies were performed in selected cases. Dogs undergoing anaesthesia for non-noisy procedures were potential controls. Dogs known (from their history) to be deaf or known to have a history of ear disease were excluded. Clinical data on dogs which had been selected for the study was recorded; including, age, sex, breed and bodyweight. Drugs used for the anaesthetic of the dogs were recorded. Dogs were tested after induction, immediately prior to MRI scanning or other procedure, and again immediately post MRI or at the end of anaesthesia. Anaesthesia was not prolonged as a result of DPOAE testing in any of the dogs, as the test was performed during preparation for their procedure and during recovery from anaesthesia.

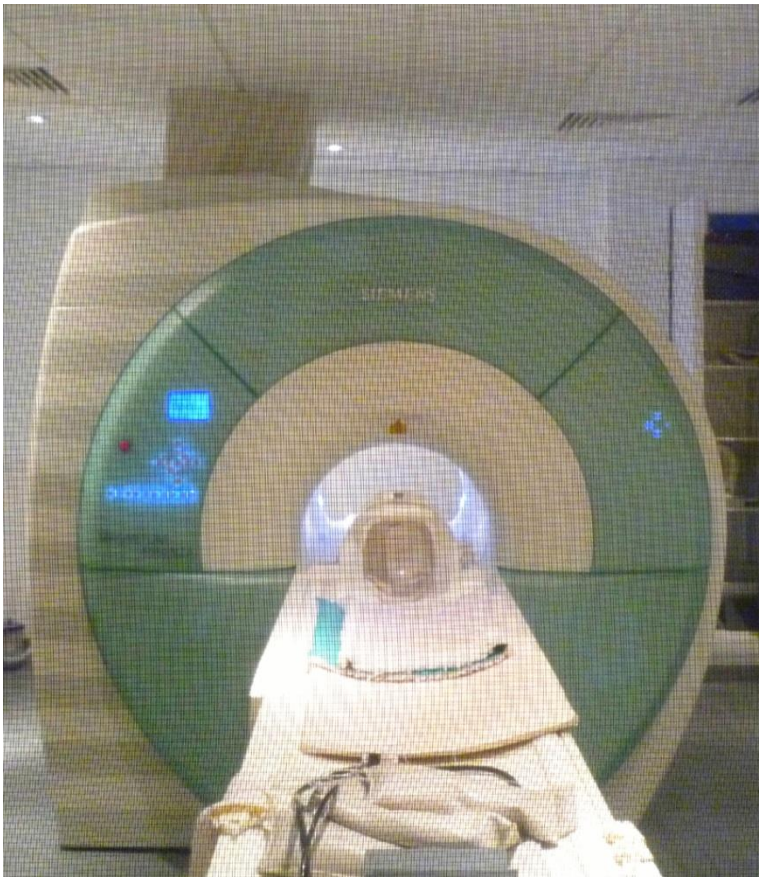

Figure 5: University of Glasgow, Small Animal Hospital's MRI scanner, used for diagnostics.

2.2 Distortion Product Otoacoustic Emissions Testing

All OAE testing was performed by a single investigator (RV), using the Echoport ILO 288 USB II system with v6 software (Otodynamics, Hatfield, UK) on a laptop computer. Each day prior to testing any dogs, the OAE probe (UGD DPOAE probe; Otodynamics, Hatfield, UK) was calibrated (using the software's calibration function and a probe test cavity). After induction and intubation, an otoscopic examination was performed. Any cerumen or debris was cleaned away using a dry swab.

A clean probe tip of appropriate size was used for each patient. The probe was inserted into the first ear and the position adjusted until the best possible fit was achieved, as determined by the OAE machine's Checkfit function. A good probe fit was indicated by a

short positive and then negative deflection in the waveform tracing, and by a smooth curve in the frequency spectrum.

DPOAE testing was then performed with fourteen frequency pairs per octave (f_1 and f_2); f_2 = 0.84kHz, 1.00Kz, 1.18kHz, 1.42kHz, 1.69kHz, 2.00kHz, 2.38kHz, 2.83kHz, 3.37kHz, 4.00kHz, 4.761kHz, 5.65kHz, 6.73kHz and 8.00kHz,. The frequencies of the two stimuli were set at a ratio of 1.21 ($f_2>f_1$) and the intensity level of both stimuli (L_1 and L_2) were set at 55dB SPL (sound pressure level). Each frequency pair was delivered to the ear for 1.5 seconds and the OAE equipment recorded evoked emissions at a third frequency ($2f_1$-f_2) as well as the level of background noise around this frequency. The frequency pairs were played in sequence from highest to lowest, lasting a total of 63 seconds, and this was defined as a "run". All tests were performed in a clinical environment, but extraneous noise was kept to a minimum. A noise-reducing cover (ear muff EP-101; Parkson Safety Industrial Corporation, Taipei, Taiwan) was placed over the test ear throughout the DPOAE testing, to reduce the effect of any environmental noise.

After each test, the probe was removed from the ear and the coupling tubes (disposable pieces which function to prevent debris from entering and damaging the OAE probe) were checked for blockage by debris. If any of the coupling tubes were blocked, they were replaced, the first result was discarded and the test was repeated on that ear. The test was repeated on the second ear, time permitting.

After the clinical procedure DPOAE testing was repeated during recovery from anaesthesia. A note was made of the length of time for which dogs were in the MRI scanner, the length of time between leaving the scanner and having the post-MRI test, the length of time between pre and post DPOAE tests (for MRI and control dogs), and the reason for MRI or anaesthesia.

2.3 Data Analysis

The OAE testing software automatically rejected data for a frequency pair during any time that the background noise exceeded a pre-defined threshold. If this occurred for all three times that the individual frequency pair was presented, then no data was collected for that frequency. If a run had more than six frequencies pairs (out of fourteen) with no data, the run was excluded. Tests in which run time was not between 60 and 66 seconds (normal run time +/- 3 seconds) were excluded. Ears were only included in the results if both a pre- and post-MRI (or at beginning and end of anaesthetic, for control dogs) reading had been obtained in that ear.

For each ear tested, the difference in absolute DPOAE between the pre- and post-procedure test was calculated for each frequency, and expressed as the mean change in DPOAE value (±SEM) for that frequency, with significance calculated using the Mann-Whitney *U* test. Significance in all statistical tests was defined as the two-tailed $P<0.05$.

The DPOAE values for each ear at each frequency were also classified as 'decreased' or 'not decreased' when comparing the absolute DPOAE between the pre- and post-procedure test. When examining the change in absolute DPOAE following a procedure under anaesthesia, random sample distribution would predict a distribution of 50% of ears demonstrating a decrease ('decrease in absolute DPOAE') and 50% demonstrating an increase ('no decrease in absolute DPOAE') in absolute DPOAE because the sensitivity of the test makes an identical value very unlikely. The percentage ears demonstrating a decrease in hearing following the MRI study at each of the fourteen frequencies assessed was compared to the control group using the chi-squared test.

The difference in absolute DPOAE between pre- and post- procedure at each frequency was calculated. If there was a difference of greater than 6 dB between post and pre

DPOAE in a frequency, this was considered a relevant change. If overall at least eight out of the fourteen frequencies (i.e. 57.1%) had decreased post MRI (or post-control procedure), the ear was awarded an overall decrease ('decreased cochlear function'). If overall at least eight frequencies had increased, the ear was awarded an overall increase ('improved cochlear function'). For any other result, the ear was considered not to have changed ('no change in cochlear function'). There is currently no widely accepted standard pass criteria for DPOAE testing in dogs, so this criteria was chosen to be as close as possible to the criteria chosen by Wagner et al. (2003), who suggested that a change in DPOAE emission amplitude of 6dB or greater, following MRI, was a relevant change, and Goncalves at al. (2012) who suggested an ear was awarded as "pass" if the absolute DPOAE detected was louder than the background noise level in at least five of the eight frequency pairs they tested (i.e. 62.5%). The proportion of ears demonstrating a decrease in hearing following exposure to MRI noise was compared to the control group using the chi-squared test.

Finally, a simple analysis was carried out to examine effects of time in the MRI scanner, in terms of counts of ears exhibiting an overall decrease in performance, using the Freeman-Halton extension of Fisher's exact probability test for a two-row (decrease/no change) by three-column (short, medium, long duration) contingency table. Durations were defined as follows: short 33-53min (N=19); medium 54-74 min (N=12); long <74 min (N=5). Data for left and right ears were analysed separately.

3. Results

3.1 Subjects

Thirty-six dogs were included in the MRI group (mean age 3.9 years, median age 3 years, range 6 months to 10 years; mean bodyweight 16.9 kg, median bodyweight 13.8 kg, range 3.5 kg to 40.8 kg) and 17 dogs were included in the control group (mean age 6.2 years, median age 7 years, range 1 year to 12 years; mean bodyweight 25.1 kg, median bodyweight 23.6 kg, range 6.7 kg to 57.8 kg). There were 16 male dogs in the MRI group (44.4%) and 10 male dogs in the control group (58.8%). A variety of dog breeds were represented, with those represented more than once including three toy poodles, three Lhasa Apso dogs, four Labrador retrievers, two cocker spaniels, four Cavalier King Charles spaniels, two boxers and three cross-breeds in the MRI group, and two Labrador retrievers and two cross-breeds in the control group.

A variety of drugs were used for premedication of the MRI group dogs, including combinations of Acepromazine (n=17), Buprenorphine (n=2), Butorphanol (n=26), Medetomidine (n=12), Methadone (n=7), Midazolam (n=1), Dexmedetomidine (n=2) and Pethidine (n=1). Drugs used for premedication of the control group dogs included combinations of Acepromazine (n=9), Butorphanol (n=2), Medetomidine (n=4), Methadone (n=8), Morphine (n=2), Alfentanil (n=5) and Atropine (n=5). The majority of dogs in both groups were induced with Propofol (32/36 in the MRI group and 15/17 in control group), the remaining dogs in both groups were induced with Alfaxalone. Isoflurane was used to maintain anaesthesia in all MRI dogs and 11/17 control dogs. The remaining control dogs were maintained with Sevoflurane.

In the MRI group, twenty dogs (55.5%) underwent imaging of the brain, fifteen (41.6%) imaging of the vertebral column and one (2.7%) imaging of the shoulder. The mean MRI

study duration was 56 minutes (median 51 minutes, range 33 minutes to 1 hour 55 minutes). The control dogs underwent anaesthesia for radiography (n=3), computed tomography (n=2), ultrasonography (n=2), radiotherapy (n=5) and surgical procedures (n=8).

Thirty MRI dogs had both ears tested and six had only one ear tested, giving a total of 66 ears (33 left and 33 right). Eleven control dogs had both ears tested and six had only one ear tested, giving a total of 28 ears (14 left and 14 right).

Dogs in the MRI group were tested a mean time of 5 minutes after leaving the MRI scanner (median time 2 minutes; range: 0 to 38 minutes). The mean time between pre- and post-MRI DPOAE tests for dogs was 1 hour 13 minutes (median time 1 hour 4 minutes; range: 41 minutes to 2 hours 13 minutes). Mean time between the DPOAE tests at the start and end of anaesthesia in the control group was 1 hour 30 minutes (median time 39 minutes; range: 13 minutes to 3 hours 59 minutes).

3.2 DPOAE results

In the MRI group, the mean change in absolute DPOAE (pre- to post-MRI) is less than 0 at all 14 frequencies (range: -2.04 to -5.01), whereas in the control group the change in DPOAE (pre- to post-procedure) fluctuates around 0 (range: 1.55 to -2.11) (Figure 6). In addition, the mean change in absolute DPOAE is always lower in the MRI group than the control group. This effect was significant at 5 f_2 frequencies out of the 14 frequency pairs tested; f_2 = 0.84 kHz (*P*=0.0477), 1.00 kHz (*P*=0.0271), 1.18 kHz (*P*=0.1096), 1.42 kHz (*P*=0.4295), 1.69 kHz (*P*=0.101), 2.00 kHz (*P*=0.2263), 2.38 kHz (*P*=0.1527), 2.83 kHz (*P*=0.1416), 3.37 kHz (*P*=0.2077), 4.00 kHz (*P*=0.0054), 4.76 kHz (*P*=0.0041), 5.65 kHz (*P*=0.1556), 6.73 kHz (*P*=0.0193) and 8.00 kHz (*P*=0.849).

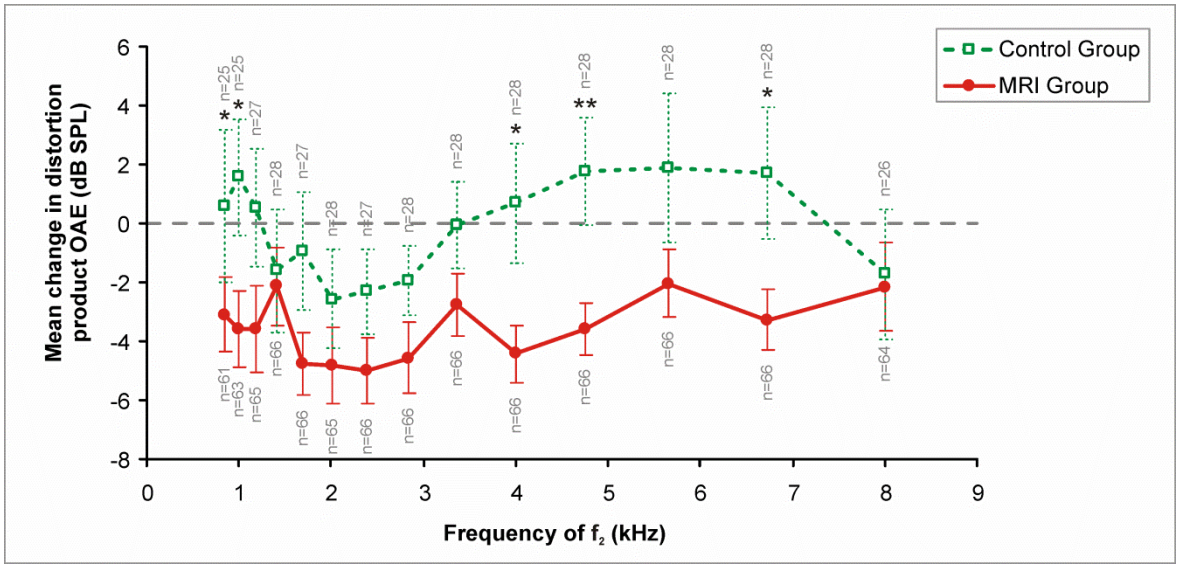

Figure 6 Effects of magnetic resonance imaging noise on cochlear function across all the frequencies tested compared to a control group having a quiet procedure under a similar length of general anaesthesia. The data shown are mean (±SEM) changes in the distortion product otoacoustic emission (DPOAE) (significance of P<0.05 denoted by * and significance of P<0.005 denoted by **). In some ears, no data was collected at certain frequencies; 'n' represents the number of ears included in the mean change in DPOAE at each frequency, for the control group and the MRI group.

At all frequencies tested, more than half of the ears exposed to MRI noise (MRI group) demonstrated a decrease in absolute DPOAE after noise exposure (Figure 7A). In the control group, no consistent pattern of change was seen across the frequencies (figure 7B). This effect was significant at 4 f_2 frequencies out of the 14 frequency pairs tested; f_2 = 0.84 kHz (χ^2 = 2.26, *P*=0.1029), 1.00 kHz (χ^2 = 4.3, *P*=0.0381), 1.18 kHz (χ^2 = 0.46, *P*=0.4976), 1.42 kHz (χ^2 = 2.14, *P*=0.1435), 1.69 kHz (χ^2 = 0.4, *P*=0.5271), 2.00 kHz (χ^2 = 0.41, *P*=0.522), 2.38 kHz (χ^2 = 1.05, *P*=0.3055), 2.83 kHz (χ^2 = 0.88, *P*=0.3482), 3.37 kHz (χ^2 = 1.0, *P*=0.3173), 4.00 kHz (χ^2 = 8.03, *P*=0.0046), 4.76 kHz (χ^2 = 7.25, *P*=0.0071), 5.65 kHz (χ^2 = 0.74, *P*=0.3897), 6.73 kHz (χ^2 = 6.84, *P*=0.0089) and 8.00 kHz (χ^2 = 0.03, *P*=0.8625).

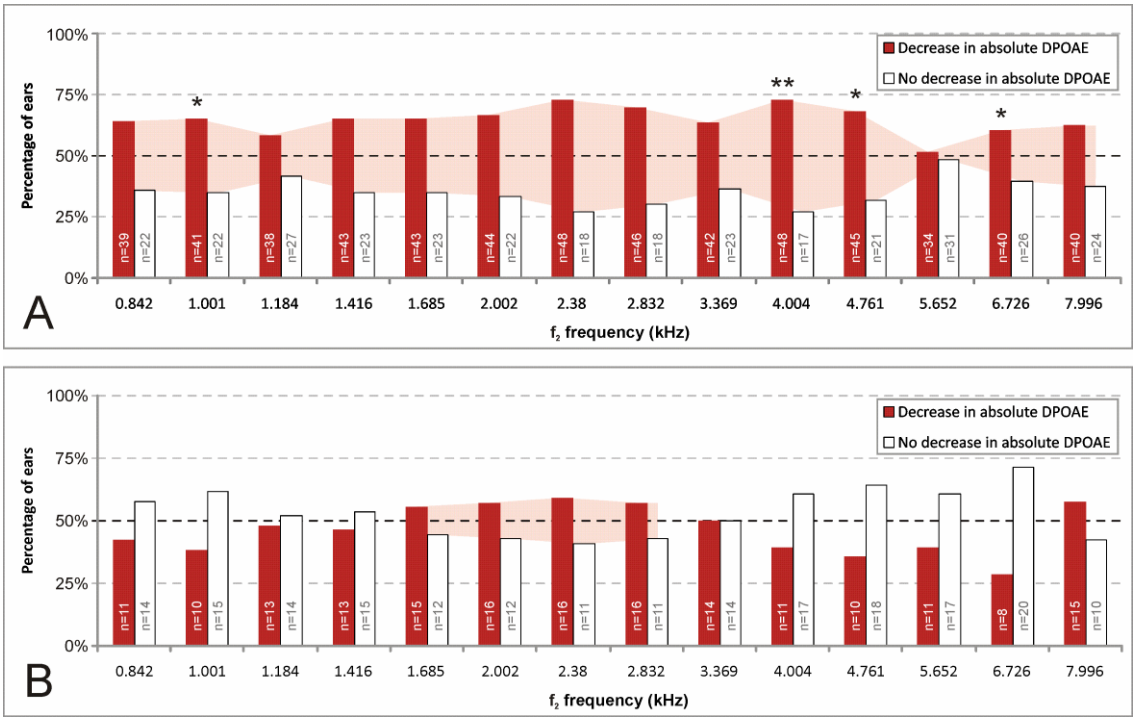

Figure 7: Percentages of ears showing a decrease or no decrease in absolute DPOAE, at all frequency pairs tested in the dogs exposed to MRI (A) or a quiet procedure (B).

When the overall effect of MRI noise on cochlear function in an individual ear was examined, substantially more ears demonstrated a decrease in overall DPOAE following exposure to MRI noise (MRI group) when compared to the control group, although this result was not significant. Twenty-one ears (31.8%) in the MRI group, versus four ears (14.3%) in the control group decreased in cochlear function (χ^2 = 2.26, *P*=0.1328) (Figure 8). One ear (1.5%) increased post-MRI, versus two ears (7.1%) in the control group. Forty-four ears (66.7%) in the MRI group and 22 ears (78.6%) in the control group showed no change in cochlear function upon the second test (after MRI or control procedure). Finally, there was no effect of time in the MRI scanner in terms of counts of ears showing an overall decrease in performance.

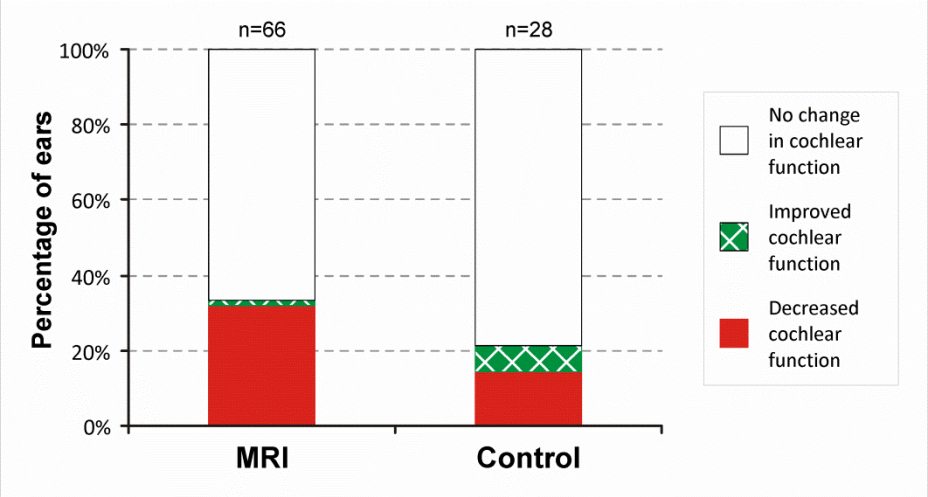

Figure 8: The overall effect of MRI noise on cochlear function in individual ears.

4. Discussion

Studies which have assessed the effect of MRI acoustic noise on cochlear function and hearing in humans have found changes to be a small (Radomskij et al., 2002) and temporary, returning to normal threshold level within 5-20 minutes (Brummett et al., 1988; Zwicker et al., 1990). There are no reports of permanent hearing loss in humans post-MRI (Brummett et al., 1988).

Prior to this study, no researchers had looked directly at the effect of acoustic noise produced by MRI scanners on the cochlear function of dogs. Lauer et al (2012) found that numerous MRI scanning protocols reach extremely high levels relative to many animals' hearing thresholds, including dogs, which had the potential to damage their cochlear function and impair hearing.

The results of this study show that exposure to MRI noise resulted in a significant reduction in the DPOAE response across a broad range of frequencies, whereas anaesthesia performed as part of quiet procedure did not result in a similar reduction in hearing. When the global effect on an individual ear was examined (by analysing all 14 frequencies in an ear, rather than assessing the effect on specific frequencies) a marked trend towards a reduction in hearing was evident, although this effect was not significant. It is well established in human patients that exposures to excessive noise for a prolonged period, or on repeated occasions, can result in permanent noise-induced hearing loss (Williams et al., 2010). Hearing loss due to excessive noise tends to affect higher frequencies first (Sjaastad et al., 2003), however within the present study the highest frequencies tested did not demonstrate the largest decrease in DPOAEs post-MRI. One possible explanation is that exposure to specific frequencies of noise may result in hearing loss specific to those frequencies. Lauer et al. (2012) determined that noise produced by

MRI scanners has a broad peak, with a maximum intensity at approximately 1.5 kHz (Figure 9). Three of the five frequencies which our study found to have a significantly lower mean change in absolute DPOAE in the MRI group than the controls (1.00kHz, 4.00kHz and 4.76kHz) were within the peak frequency range which Lauer et al stated. However, it has also previously been found that the greatest reduction in DPOAE amplitude following noise exposure occurs at approximately half an octave above the frequency of the noise (Engdahl and Kemp, 1996).

A second possible explanation may have been that the DPOAE frequencies assessed did not include high enough frequencies relevant to the hearing spectrum of canine patients. Dogs can hear sounds up to 40 kHz (Sjaastad et al., 2003) but the highest frequency tested in this study was 5.2 kHz (f_2=8.00 kHz and we were measuring at $2f_1$-f_2), due to the limitations of the equipment, and it may therefore be useful to assess cochlear function in dogs up to a higher frequency in order to assess the full effect of excessive noise on hearing loss in dogs. The frequencies tested in this study did however include the frequencies of speech, which is particularly important for dogs to be able to hear their owner's commands.

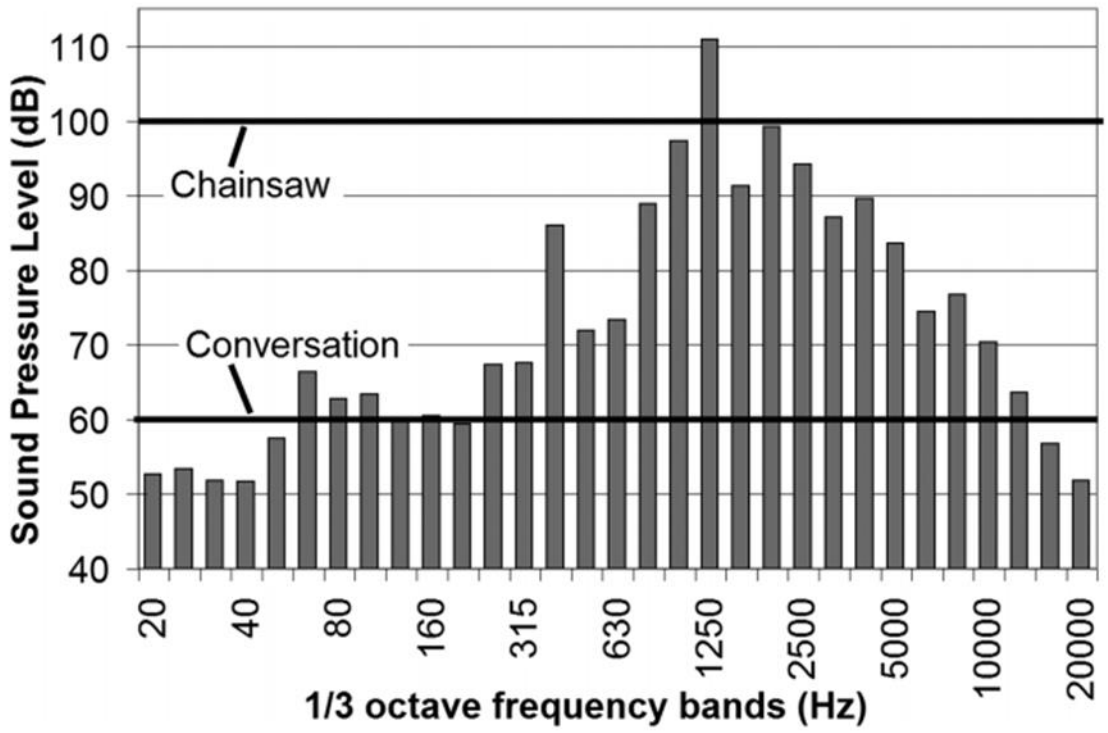

Figure 9: Unweighted acoustic noise levels (sound pressure level) produced by a multi-slice TFE sequence, in an animal scan protocol. From: Lauer et al, 2012.

The decrease in absolute DPOAEs post MRI indicates damage and/or loss of cochlear outer hair cells (Brown et al., 1989; Schrott et al., 1991), which are responsible for the production of otoacoustic emissions. It has been shown in guinea pigs that excessive noise causes degeneration of cochlear hair cells (Spoendlin and Brun, 1973). It can therefore be deduced that in this study, the reduction in DPOAEs post-MRI is most likely due to damaged and lost hair cells, as a result of the excessive noise levels to which the dogs were exposed whilst undergoing an MRI scan. Furthermore, a greater reduction in OAE amplitude in has been shown in human patients which underwent an MRI scan, versus controls (Radomskij et al., 2002).

The study included a control group of dogs undergoing anaesthesia for quiet procedures. This controlled for any potential deleterious effect of anaesthetic drugs on hearing and within-animal variation, by repeat testing the same dogs. Anaesthesia is thought to potentiate noise-induced hearing loss by diminishing the middle ear reflex (Borg and Moller, 1967; Borg and Moller, 1975) and medial olivocochlear reflex (Boyev et al., 2002; Guitton et al., 2004). Various drugs were used to pre-medicate, induce and maintain anaesthesia in both the MRI and control dog groups. The effects of anaesthetic drugs would be better controlled by consistently using the same drugs, however since this study was performed in a real working veterinary environment, it was not feasible for all dogs to be given the same anaesthetic agents.

A limitation of this study is the variation of length of time the dogs spent in the MRI scanner and also no record was kept of the sequence setting which each of the dogs were subjected to, or precisely how long they were exposed to acoustic noise levels within the MRI. MRI sequences have periods of quiet as well as periods of noise (Wagner et al., 2003) and different sequences produce different levels of acoustic noise (Lauer et al., 2012; Wagner et al., 2003), meaning that not all dogs in this study had the same degree of acoustic exposure. Furthermore, the patient positioning within the MRI scanner was not controlled for and no record was kept of which ear of the dog was uppermost within the MRI scanner in lateral recumbency. The level of cochlear damage and hearing impairment is affected by the patient positioning in the MRI, with the patient's head inside the magnet bore leading to the highest noise exposure (Wagner et al., 2003) and presumably the uppermost ear receiving a higher level of noise exposure. Finally, although no effect of duration in the MRI scanner was found, this calculation was based on counts of ears overall decreasing in cochlear function, and a more detailed analysis may have showed a

difference. Furthermore, only five dogs were in the scanner for a long period (more than 4 minutes), so sample size may have been too small to determine an effect.

Currently dogs are not usually provided with hearing protection for undergoing an MRI scan. Individuals vary in their sensitivity to loud noise but susceptibility to noise induced hearing loss cannot be predicted (Lauer et al., 2012; Radomskij et al., 2002) so it would be beneficial to provide all patients with hearing protection, such as ear plugs, whilst undergoing an MRI scan. Brummett et al (1988) found that earplugs attenuated the noise in most of the patients undergoing MRI, preventing temporary threshold shifts. Despite the use of sound dampening head support or ear protectors, Wagner et al (2003) found a significant increase in the variability (increase and decrease) of the DPOAE amplitude, post-MRI in human patients. This effect indicates more subtle changes in cochlear function than a decrease in mean DPOAE amplitude, but it suggests that ear protection alone may not be enough in some cases. Well-fitting earplugs can provide 20-30dB of attenuation (Lauer et al., 2012) however they are only beneficial if inserted correctly (Radomskij et al., 2002).

This study assessed the short-term effect of excessive MRI noise on the DPOAE response and demonstrated a significant detrimental effect on cochlear function. What is not evident from the present study is the longer-term effect of excessive MRI noise on cochlear function and it would be worthwhile to evaluate dogs some time after exposure to MRI noise to see if the effect is permanent or whether it is temporary and reversible (Brummett et al., 1988). Of more concern, is evidence that noise-induced cochlear hair cell loss may demonstrate progression for some time after the time of exposure to the excessive noise (Yamashita et al., 2004). Retesting of the MRI group 7 to 10 days after the MRI study may

have resulted in an even greater reduction in the post-MRI DPOAE. However, as this would require an additional anaesthetic, this was not feasible as part of the present study.

5. Conclusions

The results from this study indicate that exposure to noise during MRI in dogs results in a reduction in cochlear function, which is significant at multiple sound frequencies. However it is not known whether this effect is reversible or permanent. Evidence from human MRI noise exposure would suggest that this effect is temporary. The frequency region affected is likely influenced by the frequency of the noise spectra of the MRI. The demonstration that MRI noise results in some degree of hearing loss, albeit only assessed in the immediate post-MRI period in the present study, would suggest that all dogs having MRI studies performed should have ear protection as a standard precautionary measure.

Chapter 3: The Effects of Kennel Noise on Cochlear Function in Dogs

Abstract

Dog kennels are extremely noisy environments, primarily due to continuous barking and the use of construction materials which intensify acoustic noise levels. The aim of this study was to assess effects on canine cochlear function by Distortion Product Otoacoustic Emissions (DPOAE) testing dogs residing in a rehoming kennel environment for varying lengths of time (1-2 weeks; 2-4 weeks; and > 4 weeks). Dogs which had lived in kennels for more than 4 weeks had reduced mean absolute DPOAEs at all frequencies tested, significantly so at 5 out of the 14 frequencies (between 4kHz and 8kHz), reflecting a reduction in cochlear function. The reduction in cochlear function of dogs chronically exposed to loud kennel noise highlights an important welfare concern and supports the idea that more emphasis should be placed on increasing noise-dampening measures in the kennel environment. The results suggest that, where possible, dogs should be kept in the kennel environment for no more than 4 weeks, in order to minimise cochlear damage.

1. Introduction

A large proportion of dogs spend at least a short time in kennels at some point in their life which may be for various reasons, such as boarding, re-homing, for veterinary treatment or research. Introduction to kennels is a very stressful process for dogs, due to experiencing a novel environment (Rooney et al., 2007), loss of control over their environment (Hennessy et al., 1998), having social isolation from humans (Coppola et al., 2006b) and from other dogs (Wells and Hepper, 1998) and finally, due to very high noise levels (Sales et al., 1997). Numerous studies have investigated the degree of noise present in dog kennels (Coppola et al., 2006a; Sales et al., 1997; Scheifele et al., 2012); however to date, only one has looked at the effect of the noise on hearing in dogs (Scheifele et al., 2012) and none have investigated specifically the effect of noise on cochlear function of dogs living in kennels. Every effort is made to ensure that noise-induced hearing loss is avoided in the workplace for humans, for example, the noise levels in some dog kennels are so loud that, by Health and Safety Executive noise regulations (website 3), staff are required to wear ear protection whilst at work. However, the effects which the noise could be having on the dogs are often over-looked and there are currently no animal welfare policies regarding acceptable sound levels in dog kennels. Most kennels have a diurnal pattern of noise (loudest during the day and constant low-frequency noise overnight). In one study (Sales et al., 1997) it was found that noise overnight in kennels was equal to a continuous level of 60 to 85 dB, peaking at as much as 70-120dB. During the day sound levels fluctuated more, but were equal to a continuous level of between 65 and 100dB and peaked between 80 and 125dB. Most of the noise was due to barking. Sometimes excessive barking was stimulated by noisy cleaning procedures (e.g. pressure hoses), as well as in anticipation of feeding time, or people entering the kennel block. In another study (Scheifele et al., 2012), sound levels in dog kennels were found to be equal to a

continuous noise level of between 102dBA and 110dB. Excessive exposure to this degree of noise is known to be damaging to the cochlea in the inner ear of humans and could potentially result in hearing loss (Tripathy, 2011). The noise was attributed to ventilation, kennel gates, barking, daily cleaning and husbandry procedures and reverberation of noise in the echoic kennel blocks (Scheifele et al., 2012). The primary concerns in kennel design tend to be ease of cleaning and durability and consequently, typical construction materials are concrete and metal; the compromise of this being excessive noise levels.

Considering that these levels are loud enough to require humans to wear ear protection, it is extremely likely that there is also an impact of this noise on dogs. Scheifele et al (2012) examined a group of 22 dogs, which were kept together in a typical kennel environment and tested for hearing ability (using the brainstem auditory evoked response, BAER, method) after 48 hours, 3 months and 6 months of arrival. It was found that after 3 months and 6 months, all dogs included in the study had poorer hearing (indicated by a change in the wave V of the BAER waveform), than when assessed 48 hours after arrival. In the same experiment, the noise levels were monitored in the kennel area and it was found that the dogs were exposed (during the daytime) to continuous noise levels of >100dB. It was not confirmed whether the hearing loss in these dogs was permanent or temporary. To determine this, the dogs would need to have their hearing reassessed after a period of at least 14-16 hours out of noise exposure (Scheifele et al., 2012). A limitation of this study is the use of BAER testing in order to assess noise-induced hearing loss, as this approach does not specifically measure the function of the cochlea, which is often damaged as a consequence of excessive noise (Yamane et al., 1995). Otoacoustic emissions (OAE) testing is a better way of assessing specifically the integrity of cochlear outer hair cells (Goncalves et al., 2012) which are damaged by excessive noise exposure.

If kennel noise was found to have a deleterious effect on the cochlea of dogs, this could have important welfare implications. It may also be important to consider the design of kennels, to reduce noise levels, if a significant effect on the cochlear function of dogs is found. Apart from the welfare implications of hearing damage to the dogs, the noise in kennels could also affect the desirability of the dogs for re-homing. It is likely that high noise levels may put people off adopting and it has been observed that visitors spend less time looking around noisy kennels (Coppola et al., 2006a).

1.1 Aims

- To determine whether chronic noise exposure in dog kennels has a detrimental effect on the cochlear function of dogs living in rehoming kennels, by performing Otoacoustic Emissions Testing on dogs which have lived in kennels for varying lengths of time.
- To determine the kennel noise levels to which the dogs in this study were subjected.

2. Materials and Methods

This study was approved by the University of Glasgow Veterinary Ethics Committee and permission was received from the Scottish Society for Prevention of Cruelty to Animals (SSPCA) to work with dogs under their care.

2.1 Animals

Dogs which belonged to and lived at the SSPCA Glasgow Cardonald Centre, and were due to be neutered at the time of testing, were included in this study. Dogs (of varying age/breed/weight/sex) were included in the cochlear function part of the study and subjected to distortion product otoacoustic emissions testing (DPOAE).

The cochlear function of a group of dogs not currently living in kennels (control dogs) was assessed, also using Distortion Product Otoacoustic Emissions testing. Control dogs were dogs attending the University of Glasgow's Small Animal Hospital for treatments involving anaesthetic, in which dogs could undergo an OAE test twice (on one or both ears) without prolonging anaesthetic time.

On all dogs tested (SSPCA dogs and controls), clinical data was collected, including age, breed, sex, weight and drugs used to induce and maintain their anaesthesia. For the kennel dogs, the date at which they had arrived at the SSPCA centre was also noted and thus the length of time they had been living in kennels was calculated. Information on the kennel dogs prior to their arrival at the SSPCA could not be collected, so it was unknown whether any had a history of ear disease. However, any dogs known to have had ear infections or currently being treated for an ear infection were not included in the study.

2.2 Distortion Product Otoacoustic Emissions Testing

Dogs were DPOAE tested whilst under anaesthetia for neutering, to avoid excessive movement which could displace the probe and to avoid an unneccessary anaesthesia. All OAE testing was performed by a single investigator (RV), over approximately 11 weeks, using the Echoport ILO 288 USB II system with V6 software (Otodynamics, Hatfield, UK) on a laptop computer. Each day prior to testing any dogs, the OAE probe (UGD DPOAE probe; Otodynamics, Hatfield, UK) was calibrated. The tester then tested her own ears to make sure that the equipment was working correctly and to evaluate the day-to-day consistency of the equipment. After induction and intubation of the dogs, cerumen or debris was cleaned away from the external ear canal using a dry swab.

A clean probe tip of appropriate size was used for each patient. The probe was inserted into the first ear and the position adjusted until the best possible fit was achieved, as determined by the OAE machine's Checkfit function. A good probe fit was indicated by a short positive and then negative deflection in the waveform tracing, and by a smooth curve in the frequency spectrum.

DPOAE testing was then performed with fourteen frequency pairs per octave (f_1 and f_2); f_2 = 0.84kHz, 1.00Kz, 1.18kHz, 1.42kHz, 1.69kHz, 2.00kHz, 2.38kHz, 2.83kHz, 3.37kHz, 4.00kHz, 4.761kHz, 5.66kHz, 6.73kHz and 8.00kHz,. The frequencies of the two stimuli were set at a ratio of 1.21 ($f_2>f_1$) and the intensity level of both stimuli (L_1 and L_2) were set at 55dB SPL (sound pressure level). Each frequency pair was played to the ear and the OAE equipment recorded evoked emissions at a third frequency ($2f_1-f_2$) and the level of background noise. Each frequency pair was played three times, lasting a total of 63 seconds, and this was defined as a "run". All tests were performed in a clinical environment. A noise-reducing cover (ear muff EP-101; Parkson Safety Industrial

Corporation, Taipei, Taiwan) was placed over the test ear throughout the test, to reduce environmental noise.

After each test, the probe was removed from the ear and the coupling tubes (disposable pieces which function to prevent debris from entering and damaging the OAE probe) were checked for blockage by debris. If any of the coupling tubes were blocked, they were replaced, the results from that test discarded and a repeat test performed.

Once a successful test had been performed on the first ear, the test was performed a second time on the same ear, so that the average of the two tests could be taken, to control for any within-test variability. Following testing of the first ear, time permitting, the test was repeated in the same way on the second ear.

2.3 Kennel Noise Levels

In order to determine the approximate levels of sound which the dogs in these particular kennels were exposed to, a sound level meter (IEC651 type 2 Sound Level Meter) was used to measure the noise levels inside and outside kennel blocks. Measurements were taken at different times of day over five days, to achieve a reading for the maximum noise level (LAmax) and an average noise level (LAeq), inside the kennel and outdoors near the kennel.

The indoor measurements were taken from the end of a corridor, in which a total of twenty kennels ran down each side (Figure 10). See Appendix 2 for a diagram of the layout of the indoor kennels. Dogs in the indoor kennels also had access to individual outdoor runs during the daytime. The outdoor measurements were taken from a position halfway between two different kennel blocks (Figure 11) in which dogs had access to small individual outdoor runs on either side during the daytime; each block had nine kennels and was 5m from the tester. See Appendix 3 for a diagram of the layout of outdoor kennels.

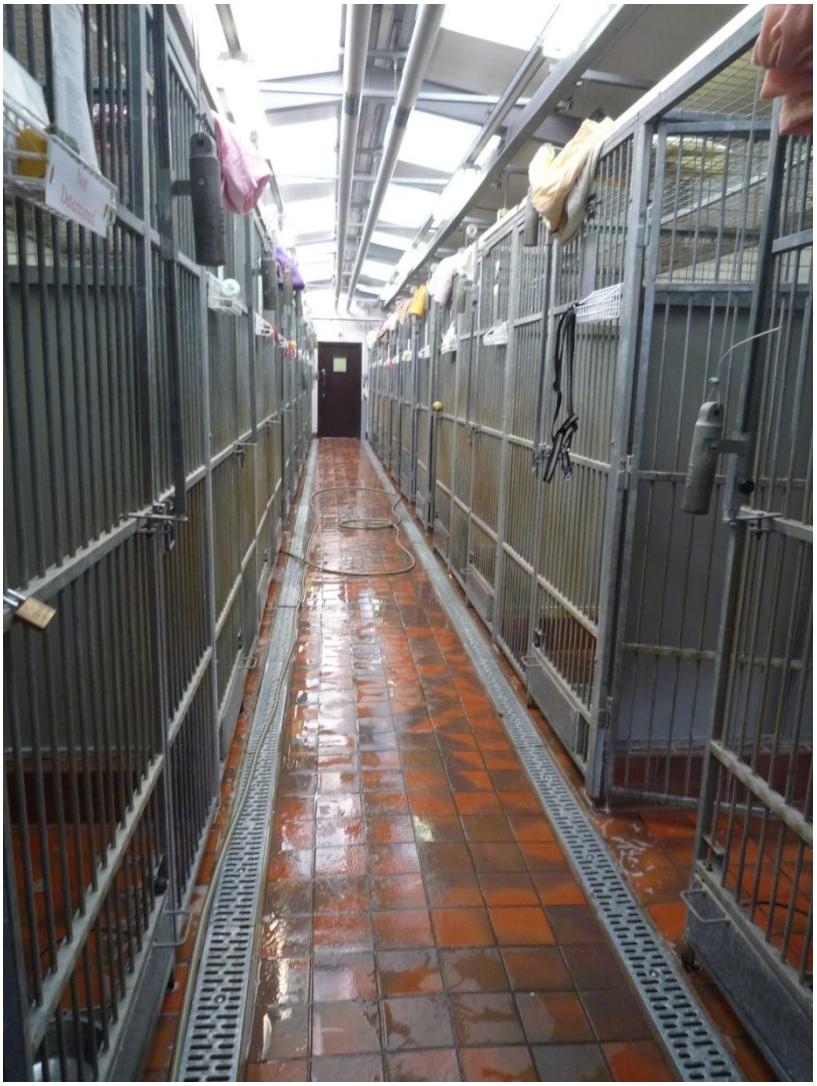

Figure 10: View from position of measuring noise levels, in indoor kennel block.

Figure 11: View from position of measuring noise levels, between outdoor kennel blocks.

Measurements of the maximum noise level (LAmax) were taken at 9am, 11am, 1pm, 3pm and 4pm. Measurements of the average noise level (LAeq) were taken at 8.30am, 9.30am, 10.30am, 11.30am, 12.30pm, 1.30pm, 2.30pm, 3.30pm and 4.30pm

It was noted which measurements were taken at feeding time, and when dogs were walked past the kennels, which may have stimulated an increase in barking and noise levels.

2.4 Statistical Analysis

2.4.1 DPOAE Test

Tests in which run time was not between 60 and 66 seconds (normal run time +/- 3 seconds) were excluded. Ears were only included in the results if two readings had been obtained in that ear. The absolute DPOAE (at each frequency pair) of the two readings for each ear were averaged. In some instances, no data was collected at certain frequencies (if background noise was too high for the OAE machine to reject), in which case the absolute DPOAE from the other reading on the same ear was used alone. There were no cases where neither of the two readings for an ear had collected data at a particular frequency.

Dogs were each allocated into one of four time groups, depending on the length of time they had spent in SSPCA kennels at the time of testing: 0 weeks (Controls); 1-2 weeks (25 dogs); 2-4 weeks (17 dogs); and >4 weeks (8 dogs).

The mean absolute DPOAE at each frequency pair was calculated, for ears of dogs which had been in kennels 1-2 weeks, 2-4 weeks and >4 weeks. Similarly, the mean sound to noise (S:N) ratio (absolute DPOAE minus noise level) at each frequency pair was calculated, for the dogs which had been in kennels 1-2 weeks, 2-4 weeks and >4 weeks. The mean absolute DPOAE and the mean S:N ratio was related to the length of time the dogs had spent in kennels by a one-way ANOVA.

For both the kennel dogs and the control dogs, for each ear, each frequency was given either a pass, if the average absolute DPOAE detected (of the two runs) was greater than or equal to 3dB SPL greater than the average background noise level detected, or a fail if not. If at least eight out of the fourteen frequency pairs passed (i.e. 57.1%), then the ear was given an overall pass; otherwise it was given a fail. There is currently no widely accepted standard pass criteria for DPOAE testing, so this pass criteria was selected to be

consistent with (Goncalves et al., 2012), who suggested an ear was awarded as “pass” if the absolute DPOAE detected was at least 3dB SPL louder than the background noise level in at least five of the eight frequency pairs they tested (i.e. 62.5%). The percentage of ears which passed and failed the DPOAE, by this criteria, was then compared to the length of time the dogs had spent in kennels: 0 weeks (controls), 1-2 weeks, 2-4 weeks and >4 weeks; by a one-way ANOVA.

2.4.2 Kennel Noise Levels

The average noise level (LAeq) was measured by taking a reading of the noise level every minute for 10 minutes, at 8.30am, 9.30am, 10.30am, 11.30am, 12.30pm, 1.30pm, 2.30pm, 3.30pm and 4.30pm. The LAeq of the ten 1-minute readings was calculated by averaging them. Since decibels are on a logarithmic scale, the readings cannot be simply averaged; they have to be converted into linear real numbers, averaged and then converted back to decibels. This was calculated on excel using the formula: =10*LOG10(AVERAGE(10^((range)/10))).

The LAmax level was recorded three times and averaged for each reading in the same way using the above formula.

3. Results

Fifty dogs living in the SSPCA kennels were subjected to OAE testing and twenty-five control dogs were also OAE tested. Due to time constraints, it was not always possible to test both ears of each dog. Hence, 95 kennel dogs' ears were tested and 38 control dogs' ears were tested.

The control dogs were DPOAE tested whilst under anaesthesia for procedures including surgery (n=10), MRI scans (n=10), radiography (n=3), radiotherapy (n=1) and CT scan (n=1). Dogs due to undergo an MRI scan were DPOAE tested prior to the scan, to avoid testing dogs with potentially reduced cochlear function due to exposure to excessive MRI noise.

Twenty-five of the SSPCA dogs had been in kennels for 1-2 weeks (range: 7–13 days) at the time of testing (48 ears were tested); 17 dogs had been in kennels for 2-4 weeks (range: 15-26 days; 31 ears tested); and 8 dogs had been in for more than 4 weeks (range: 35-67 days; 16 ears tested).

The average age of the control dogs was 6.49 years and their average weight was 18.59kg. The average age of the dogs which had been in kennels for 1-2 weeks was 2.21 years and their average weight was 16.34kg. The average age of the dogs which had been in kennels for 2-4 weeks was 3.34 years and their average weight was 17.78kg. The average age of the dogs which had been in kennels for more than 4 weeks was 3.89 years and their average weight was 15.66kg.

There were fourteen different pedigree breeds of control dogs (one Springer Spaniel, three Labradors, two Toy Poodles, one Bichon Frise, three Cocker Spaniels, one German Shepherd, one Beagle, one Bulldog, one Bearded Collie, two Shih-Tzus, one Pug, one Lhasa Apso, one Golden Retriever and one Border Collie) and there were five cross-

breeds. In the 1-2 week kennel dogs, there were ten Staffordshire Bull Terriers, three Border Collies, one Jack Russell Terrier, one Labrador and ten cross-breeds. In the 2-4 week kennel dogs, there were five Staffordshire Bull Terriers, one Jack Russell Terrier, three Rough Collies, one Boxer, one Rhodesian Ridgeback, one Cairn Terrier and five cross-breeds. In the > 4weeks kennel dogs, there were three Staffordshire Bull Terriers, one Border Collie, one Rough Collie and three cross-breeds.

Control dogs were pre-medicated for anaesthesia using various combinations of drugs including Acepromazine, Methadone, Medetomidine, Butorphanol, Alfentanil, Atropine, Morphine, Fentanyl and Buprenorphine. All kennel dogs were pre-medicated for anaesthesia with either Acepromazine and Meloxicam or Dexmedetomidine and Meloxicam. Control dogs were induced into anaesthesia using either Propofol (n=20) or Alfaxalone (n=5) and maintained using Isoflurane (n=23) or Sevoflurane (n=2). All kennel dogs were induced using Propofol and maintained with Sevoflurane.

3.1 Distortion Product Otoacoustic Emissions Testing

The dogs which had been in kennels for more than 4 weeks (at the time of testing) had a lower absolute DPOAE than the dogs which had been in kennels for 1-2 weeks and 2-4 weeks in eleven out of the fourteen frequency pairs tested, and this approached significance at f_2=2.83kHz (p=0.054), and was significant at f_2= 4kHz (p=0.034), 4.76kHz (p=0.01), 5.66kHz (p=0.004), 6.73kHz (p=0.003) and 8kHz (p=0.005) (Figure 12).

Similar to the mean absolute DPOAEs, the mean S:N ratio was lower in the dogs which had been in kennels for more than 4 weeks, compared to dogs which had been in kennels for 1-2 weeks and 2-4 weeks, in thirteen out of the fourteen frequency pairs tested. This was significant at f_2= 2.83kHz (p=0.044), 4.76kHz (p=0.016), 5.66kHz (p=0.002), 6.73kHz (p=0.006) and 8kHz (p=0.006) (Figure 13).

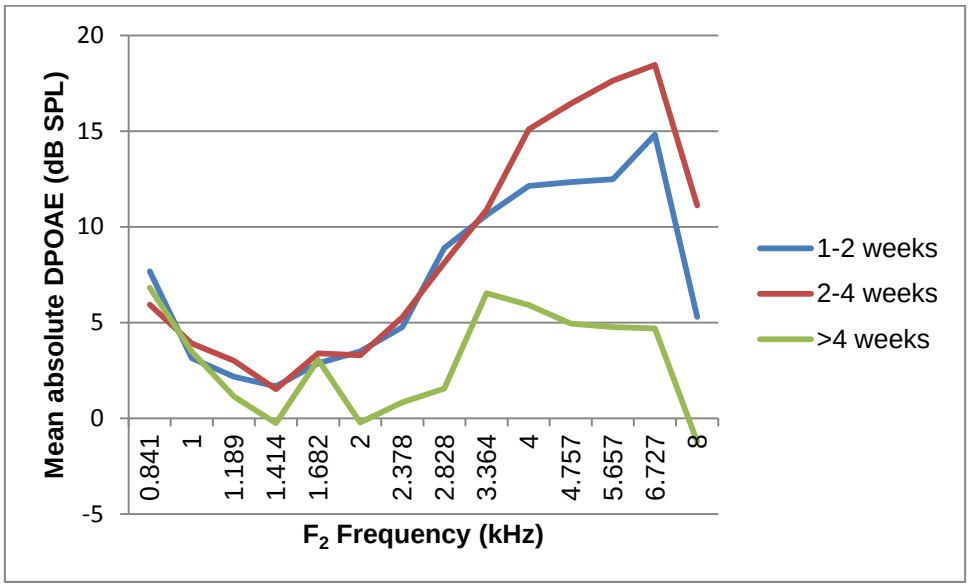

Figure 12: Mean absolute DPOAE of each of the kennel time groups, at each frequency pair tested.

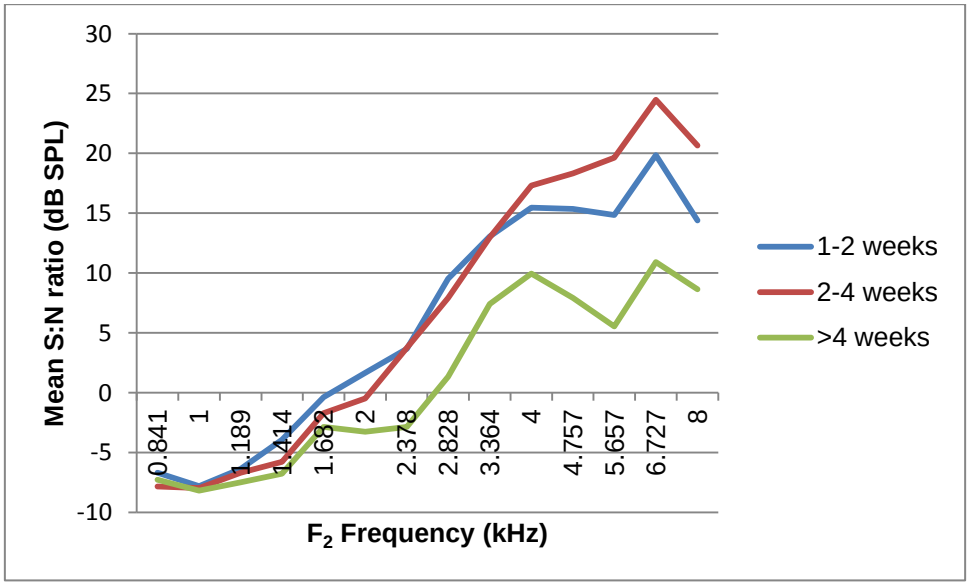

Figure 13: Mean sound to noise ratio (absolute DPOAE minus noise level) of each of the kennel time groups, at each frequency pair tested.

In the control group, 24 out of the 38 (63.16%) ears were awarded a pass (by achieving an average absolute DPOAE of at least 3dB SPL greater than the average background noise level, in at least eight out of the fourteen frequencies tested). Twenty of the 48 ears (41.67%) from the dogs which had been in kennels for 1-2 weeks, and 15 of the 31 ears (48.39%) from the dogs which had been in kennels for 2-4 weeks, were awarded a pass. In contrast, only three of the 16 ears (18.75%) of dogs which had been in the kennels for over 4 weeks were awarded a pass, which was significantly lower than the controls and the dogs which had been in kennels for 1-2 weeks and 2-4 weeks ($p=0.025$) (Figure 14). The mean number of frequency pairs passed (out of 14) by the control group was 7.58, for the dogs which had been in kennels for 1-2 weeks was 6.83, the dogs which had been in kennels for 2-4 weeks was 7.48 and the dogs which had been in kennels for more than 4 weeks was 4.63.

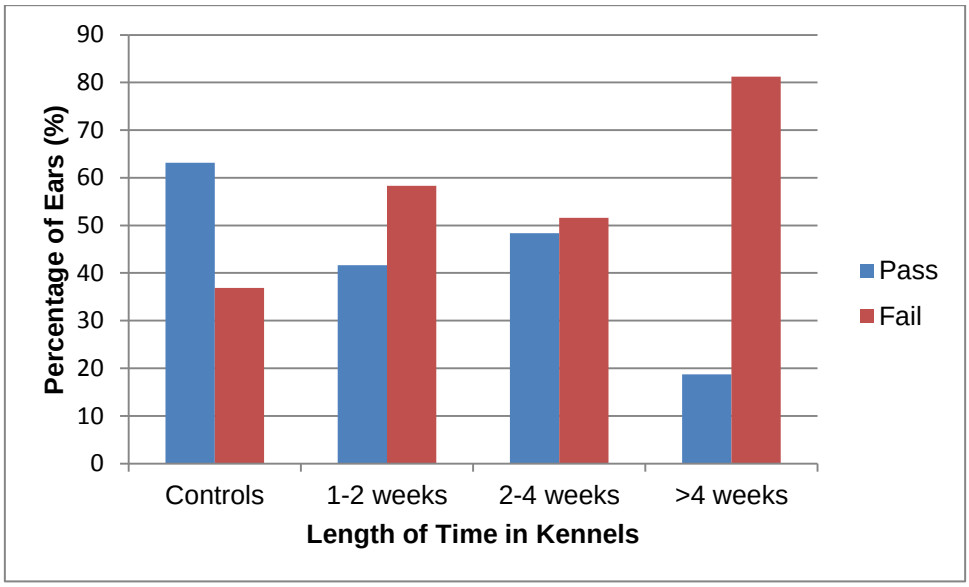

Figure 14: Percentage of ears tested achieving a pass and fail in each time group and the control group. A pass is awarded to an ear if the absolute DPOAE is at least 3 dB louder than the noise level in at least eight out of the fourteen frequency pairs tested. Control dogs were not currently living in kennels.

3.2 Kennel Noise Level

For each of the indoor measurements, there were always 19 or 20 dogs present in the kennels, which also had access to outdoors. For each outdoor measurement, there were always 18 dogs present in the kennels.

LAeq levels were calculated indoors and outdoors for every hour from 8.30am to 4.30pm, with the exception of indoors at 10.30am and 11.30am. LAeq noise levels could not be measured at the indoor runs at 10.30am and 11.30am because during this time, all dogs were shut in their individual outdoor run to allow for kennel cleaning. At almost all times of day, it was found that inside the kennel block was louder LAeq than outside (despite the fact that more dogs were present outdoors at the time of measurement) with the exception of 3.30pm where LAeq levels were similar indoors and outdoors (Table 1, Figure 15). The loudest LAeq indoors was first thing in the morning, at 8.30am, where the LAeq was 101.3dBA. For the rest of the day, the LAeq levels remained between 91.4dBA and 95.8dBA. At the time of measurement at 1.30pm and 2.30pm, it was observed that noise levels increased slightly, due to dogs being taken out of individual kennels and walked through the indoor corridor to the veterinary clinic. This observation is reflected on the graph (Figure 15), by the slightly higher LAeq points at 1.30pm and 2.30pm.

The LAeq levels outdoors fluctuated much more than those indoors. The highest LAeq outdoors was at 3.30pm (91.6dBA), which was when the dogs in these kennels were fed. LAeq was at a high point at 8.30am, again coinciding with feeding time of these dogs. At the 2.30pm readings, visitors were present; however this does not appear to have drastically increased the LAeq levels.

LAmax levels were measured indoors and outdoors at 9am, 11am, 1pm, 3pm and 4pm. Indoors, the LAmax levels were over 100dB at all times measured. The highest LAmax

level indoors recorded was 109.7dBA, at 11am. Outdoors, the LAmax levels were lower, ranging between 86.3dB (at 11am) and 93.8dB (at 9am). (Table 2)

Time of Day	LAeq indoors (dBA)	LAeq outdoors (dBA)
8.30am	101.3	88.4
9.30am	94.3	79.7
10.30am	Not measured	84.1
11.30am	Not measured	73.4
12.30pm	94.1	75.4
1.30pm	95.7	82.2
2.30pm	95.8	81.2
3.30pm	91.4	91.6
4.30pm	94.8	73.6

Table 1: The LAeq noise levels at different times of day, measured from inside a kennel block, and outside between 2 kennel blocks. No data was collect indoors at 10.30am or 11.30am because during this time everyday, the dogs are all shut outside in their individual runs to allow cleaning of the indoor kennels.

Time of Day	LAmax indoors (dBA)	LAmax outdoors (dBA)
9am	107.0	93.8
11am	109.7	86.3
1pm	101.2	89.1
3pm	104.3	93.2
4pm	102.0	89.4

Table 2: The LAmax noise levels at different times of day, measure from inside a kennel block, and outside between 2 kennel blocks.

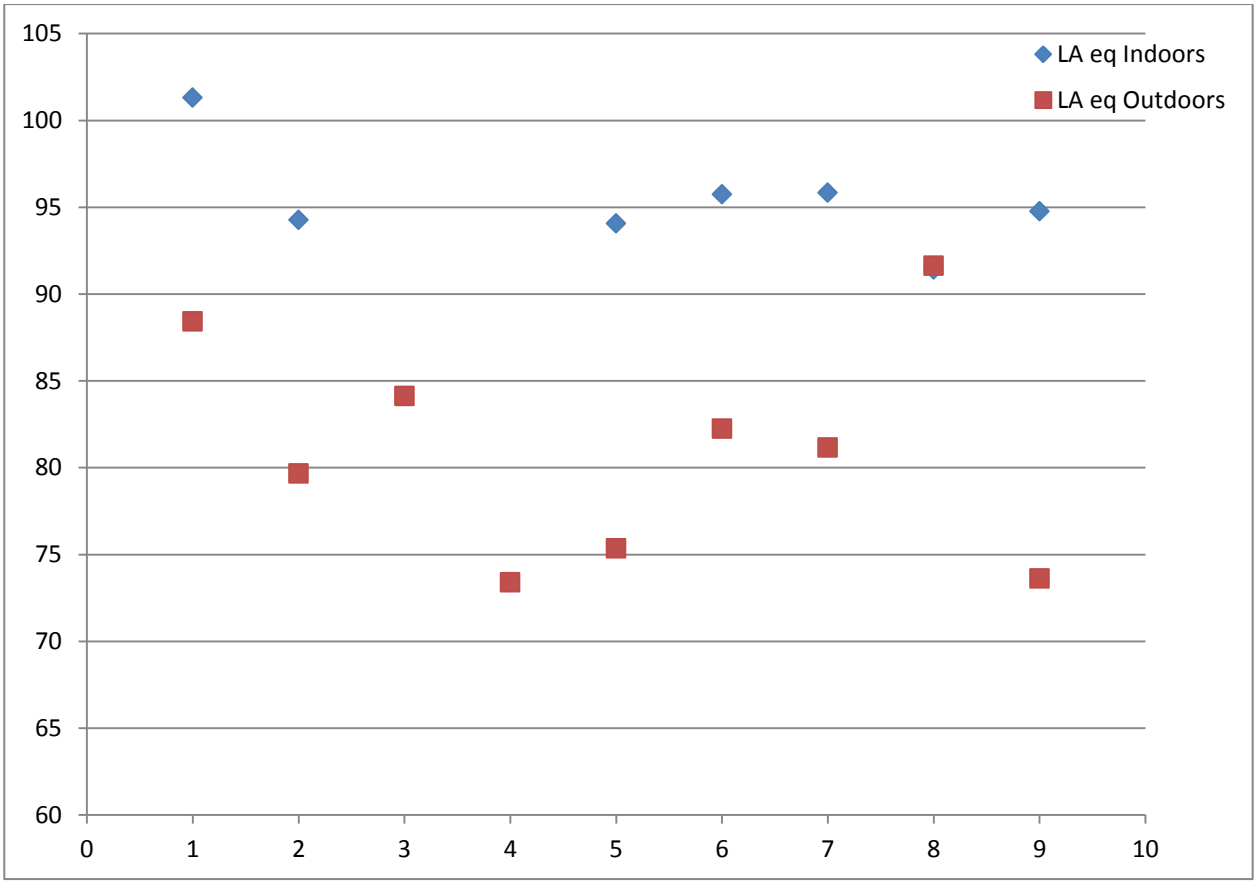

Figure 15: The LAeq noise levels at different times of day measured from inside a kennel block, and outside between 2 kennel blocks. Data from table 4. On the X-axis, 1 represents 8.30am, 2 is 9.30am, 3 is 10.30am, 4 is 11.30am, 5 is 12.30pm, 6 is 1.30pm, 7 is 2.30pm, 8 is 3.30pm and 9 is 4.30pm.

4. Discussion

Dogs are housed in kennels for a variety of reasons, including quarantine, boarding, sporting, service-work, security, military purposes, laboratory research, re-homing, veterinary treatment, teaching, breeding and assistance training (Sales et al., 1997; Taylor and Mills, 2007). Noise in kennels can reach levels which is potentially damaging to the hearing of dogs. Despite this, little research has been performed to assess the effects of the noise in the kennel environment on the auditory function of dogs.

The results from this study indicate that dogs which have lived in kennels for a period of greater than 4 weeks have a reduced cochlear function, when detecting some frequencies of sound, compared to dogs which have lived in kennels for less than 4 weeks. To date, no other studies have assessed the effect of kennel noise on cochlear function in dogs, however one other study looked at the effect of kennel noise on hearing in dogs, by Brainstem Auditory Evoked Response (BAER) testing (Scheifele et al., 2012). Scheifele et al. (2012) tested dogs upon entering the kennel environment, and again 3 and 6 months after living in the kennels. They found that after 3 months in kennels, some dogs had a shift in their hearing threshold, and after 6 months all dogs tested had reduced auditory function. A limitation of the present study, compared to the study by Scheifele et al. (2012), is that it was not feasible to test the same dogs upon entering kennels and re-test them a specific period of time later. Each of the dogs in the study was only tested on one occasion, meaning that effects of time in kennels on individual dogs could not be assessed. Nonetheless, these results add weight to the concern highlighted by them, relating to the impact of kennelling on hearing.

The longest time which any of the dogs included in the present study (at the time of testing) had spent in kennels was 67 days, which is less than the 3 month test-point in which

Scheifele et al found a reduction in auditory function in only some of their dogs. Dogs were DPOAE tested whilst under anaesthesia for neutering and the SSPCA aimed to neuter dogs within 2 weeks of arrival the kennels. Consequently, it was only possible to test a few dogs which had been in the kennels for a longer period of time. Furthermore, the history of the dogs in the present study was unknown, and it is possible that some of them had lived in kennels for long periods previously in their lives, which could have damaged their cochlear function.

The LAeq kennel acoustic noise levels measured in the present study ranged from 73.4dBA (measured between outdoor kennel blocks) to 101.3dBA (measured inside a typical kennel block). The loudest level detected (LAmax) was 109.7dBA. The noise levels measured in this study are similar to the levels detected in other studies, indicating that these were fairly typical kennel facilities. Scheifele et al (2012) measured a continuous LAeq of 100dBA in a shelter kennel. Sales et al (1997) measured LAeq levels of between 65 and 100 dBA through the day, peaking at between 85 and 125 dBA, in various dog kennel environments, including research laboratories, dog training establishments and rescue centres. A limitation of the present study was that over-night noise levels could not be determined, since the noise level meter was manually controlled. However it has been found that noise levels tend to drop overnight in dog kennels (Sales et al., 1997), and given that we were most interested in looking at peak noise levels this is probably not a problem.

Most of the noise in dog kennels occurs between 30 and 2000Hz, as a result of dogs barking (Scheifele et al., 2012). Dogs are more sensitive than humans to the frequency range of their barks (Sales et al., 1997), consequently are likely to have auditory damage if over-exposed to noise at these frequencies. In the present study, the greatest effect on cochlear function after dogs had lived in the kennel environment for more than 4 weeks

was found to occur at frequencies above 4000Hz, higher than the expected range of 30 to 2000Hz found by Scheifele et al (2012). However, due to limitations of the equipment (which measured sound level, not frequency), it was not possible to measure the frequency of the noise at these particular kennels. It is possible that the noise at these kennels was at a higher frequency than the 30 to 2000Hz measured by Scheifele et al (2012).

Currently, the effect of kennel noise on the auditory function of dogs is not a primary concern when designing a dog kennel environment and there are no policies regulating kennel noise levels (Coppola et al., 2006a). Kennels are usually built with cleanliness, durability and cost in mind, so the primary materials are concrete and metal, which increase noise levels by reverberation (Scheifele et al., 2012). Various methods have proven successful in reducing acoustic noise levels in the dog kennel environments. Restricting dogs' access to outdoor enclosures tends to result in a reduction in barking (Sales et al., 1997). Similarly, reducing the interaction dogs have with other dogs and with humans, can reduce noise levels, however this raises other welfare concerns relating to lack of socialisation of the dogs (Sales et al., 1997). Methods of reducing noise levels which do not raise welfare concerns include increasing the insulation in-between kennels (Sales et al., 1997), decreasing the reverberation of noise with sound absorption techniques (Scheifele et al., 2012), such as acoustic blankets, and playing classical music, which has a calming effect on dogs (Wells et al., 2002).

5. Conclusions

The results of this study may suggest that the cochlear of dogs which have been in kennels for more than 4 weeks have reduced ability to detect some frequencies of sound, compared to dogs which have been in kennels for less than 4 weeks, or are not currently living in kennels. This reduced function is most likely as a result of exposure to excessive acoustic noise levels in kennels, which can damage the outer hair cells of the cochlea. This finding potentially raises an important welfare concern for dogs and suggests that dog shelters should aim to re-home dogs within 4 weeks of arrival at the kennels, to minimise damage to the cochlea and potential noise-induced hearing loss.

General discussion

The aim of this project was to assess the effects of noise exposure on the cochlear function of dogs, in situations in which they are regularly exposed to extremely loud noise levels. An MRI scan is an example of an acute exposure to excessive noise levels which many dogs experience. The dogs in this study were exposed to MRI noise for an average duration of 56 minutes, but with noise levels which have been shown to peak at over 120dB (Counter et al., 2000; Radomskij et al., 2002; Wagner et al., 2003), it is perhaps unsurprising that cochlear damage was detected. By comparison, the kennel environment is a situation which most dogs face at some point during their lives, whether it is for boarding, rehoming, veterinary treatment, research, work or other reasons (Sales et al., 1997; Taylor and Mills, 2007). In kennels, dogs are exposed to high noise levels on a chronic basis, which regularly exceed 100dB (Sales et al., 1997; Scheifele et al., 2012). This study found that dogs which had lived in kennels for more than 4 weeks had reduced cochlear function versus dogs which had been in the kennels for less than 4 weeks at the time of testing.

The test used to assess the cochlear function of dogs in these studies was the Distortion Product Otoacoustic Emissions (DPOAE) test, which has been shown to be valid for use in dogs (Goncalves et al., 2012; McBrearty and Penderis, 2011). DPOAE testing is used to assess the integrity of cochlear outer hair cells (Radomskij et al., 2002). Excessive noise levels cause hearing loss by damaging these outer hair cells, which makes DPOAE testing ideal for assessing noise-induced cochlear damage. A limitation of this test is that it does not cover the full hearing range of dogs (approximately 67 to 45,000Hz (Fay, 1988)) and therefore the results of this study may not have detected the full extent of the loss in cochlear function as a result of MRI or kennel noise. The DPOAE test is also strongly

affected by background noise levels in the test environment. In humans, this test is often performed in a sound-proof room however in this project all testing was performed in a clinical veterinary environment. Background noise levels tended to mainly affect the lower frequencies tested, where low-frequency noise from the equipment humming may have at times exceeded the level of the DPOAE detected. In order to counter the environmental noise, the test room was kept as quite as possible for the duration of testing and a noise-reducing ear cover was placed over the test ear. The use of a very stringent pass/fail protocol in this project may also have classified a proportion of normal-hearing dogs as deaf. This is not particularly relevant in the MRI study, as dogs were tested twice and the difference in their cochlear function was compared between before and after the MRI scan. However in the kennel study, where dogs were only tested on one occasion, the pass criterion may have had an impact upon the results. In order to minimise inter-test variation and the effects of environmental noise, all ears included in the kennel results had been DPOAE tested twice and the results averaged. Furthermore, individual responses at each frequency were analysed and the pass/fail protocol was only used in some of the analysis.

The decision was made, in both the MRI study and the kennel study, to test both ears of each dog, where possible. Due to the fact that dogs could only be tested whilst under anaesthesia for other procedures (to avoid an unnecessary anaesthesia for the study), the number of dogs which could be tested was limited. Testing both ears of as many dogs as possible allowed an increase in the size of the data set of the studies. In the majority of cases, both ears of each dog were tested. Each ear of the same dog may vary in its hearing ability and sensitivity to loud noises (for example if cerumen is blocking the external ear canal in one ear, which could reduce transmission and intensity of the noise reaching the inner ear), and either ear could also be affected differently in the MRI scan, depending which way the dog was lying within the scanner. It was therefore problematic to arbitrarily

choose left or right ear for analysis, or to calculate averages across ears, which might produce meaningless results. Choosing 'best' or 'worst' ear was also considered, but this would have biased the results. For these reasons, analysis was carried out with ears (exposed to acute or chronic noise) rather than dogs as the statistical unit, while acknowledging that the results from each ear may not be completely independent. This approach has been used successfully in previously published work using the DPAOE in dogs (Goncalves et al., 2012; McBrearty and Penderis, 2011). Encouragingly, an exploratory analysis using responses from left ears only in the kennel noise study yielded almost identical results to the analysis based on both ears.

The dogs in the MRI study were tested in Glasgow University's Small Animal Hospital, while the kennel dogs were tested at Glasgow's SSPCA centre. Since these test environments were not exactly the same, the study results could not be directly compared. Ideally, all dogs would be tested under the same conditions and the noise levels in test environment would be measured to determine how much of an impact background noise may have had on the results.

The results of this project highlight important welfare concerns for dogs. Damage to the cochlea due to excessive noise may result in hearing loss. Dogs with reduced auditory function are at higher risks from hazards such as traffic, as well as being more likely to become startled and stressed. Deafness may also affect the temperament of dogs, for example increase their nervousness or aggression, or simply make them more difficult to train. In a dog shelter, this is particularly important because it could impact upon the dogs' chances of being re-homed. For dogs which live permanently in kennels, such as military/police dogs, there could be important implications if the dogs become less responsive to the voice commands of their handlers due to noise-induced hearing loss.

Previously, noise-induced cochlear damage and hearing loss have often not been considered in dogs, overlooking a serious potential welfare issue. The results lead to two recommendations; firstly, that a standard protocol should be to fit ear plugs or muffs to all dogs undergoing an MRI scan, as is the case with human patients. Secondly, sound-dampening measures should be fitted into current kennel environments and future kennels should be built with noise-reduction measures as a priority, and where possible, stays in kennels should be limited to less than 4 weeks.

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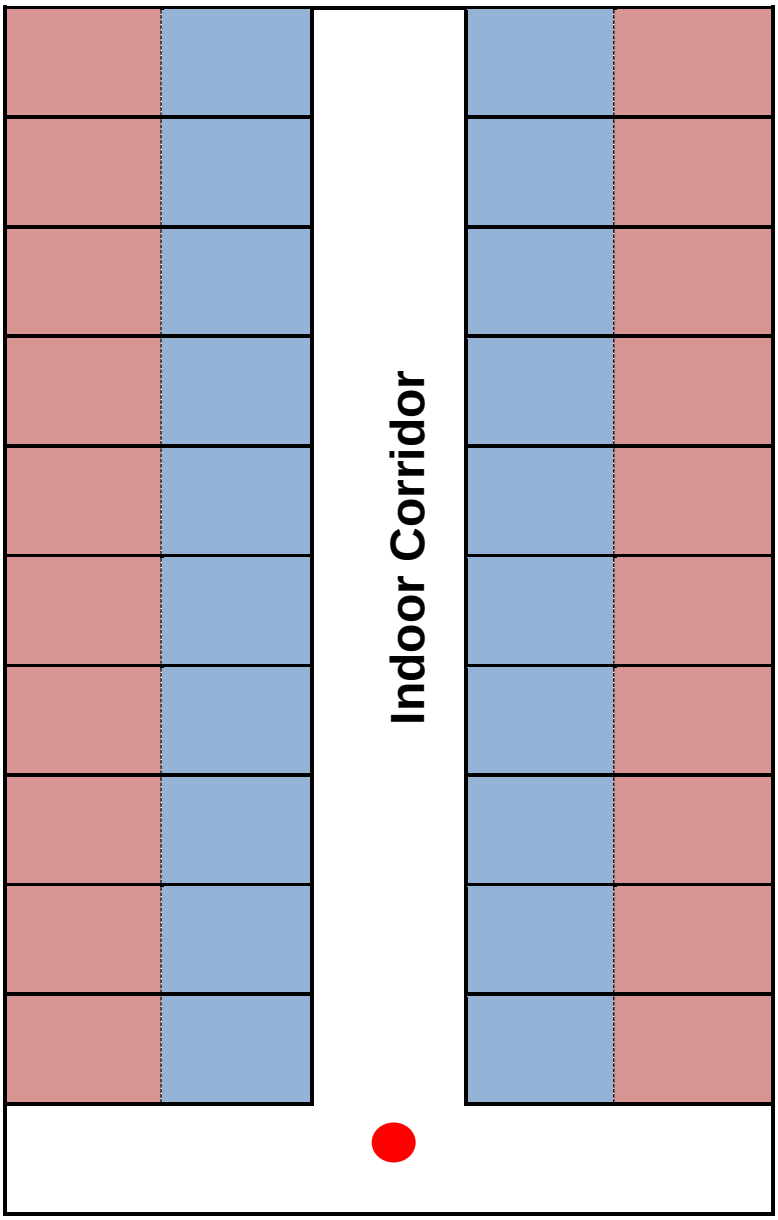
Appendices

Appendix 1

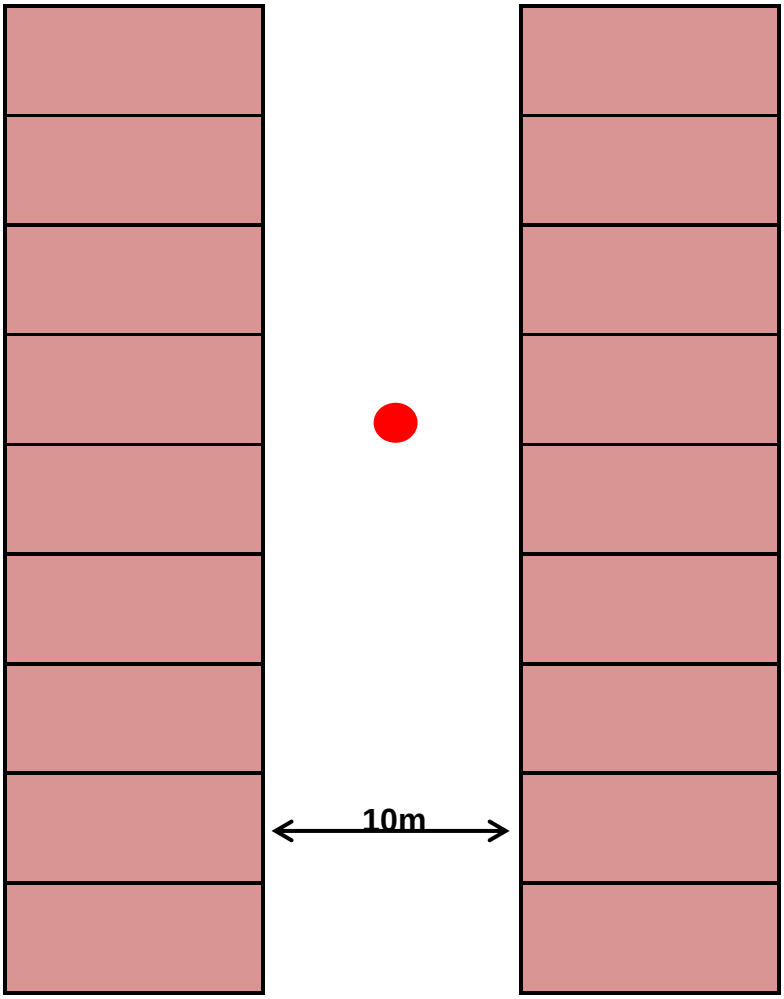
How do MRI scanners produce noise?

To understand how MRI scanners produce noise, first requires a basic understanding of how MRI scanners work. The MRI machine is a giant magnet which the patient lies within. The mammalian body contains many hydrogen atoms, which each contain one proton. When the patient is in the magnetic field, all the protons in the body line up with the direction of the magnetic field. The MRI machine applies an RF (radio frequency) pulse through a coil, in the area of the body which is to be examined. This RF pulse causes some of the protons to spin at a particular frequency and direction. At the same time as the RF pulse, 3 lower strength gradient magnets in the machine rapidly turn on and off, altering the main magnetic field on a local level. When the RF pulse turns off, the protons start to move back into their natural alignment. The coil detects this and sends data to a computer system, which is converted into a picture. An MRI scanner builds up 2-D or 3-D maps to create 2-D images or 3-D models. The extreme levels of noise produced by an MRI scanner is caused by the opposition of the main magnetic field to the changing currents of the gradient magnets, causing strong forces (called a Lorentz forces) which act upon the coils causing them to vibrate. The noise produced is a continuous, loud hammering (website 4).



Appendix 2

Layout of the indoor kennel block where noise levels were measured. The blue shading represents the indoor portion of each individual kennel and the red shading is the outdoor portion. The red dot represents the position of the tester when recording noise levels. Note: diagram not to scale.



Appendix 3

Layout of kennel blocks where outdoor noise levels were measured. The red boxes represent the kennels and the red dot represents the position of the tester when recording noise levels. Note: diagram not to scale.