Ursidae: The Undergraduate Research Journal at the University of Northern Colorado

Volume 11
Number 1 *2021/22 Full Article Issue*

Article 1

July 2022

Understanding How High Levels of Noise Affect the Equine Auditory System

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Understanding How High Levels of Noise Affect the Equine Auditory System

Exposure to brief or constant high levels of noise affects one's ability to hear, generally causing a sensorineural or, more rarely, conductive hearing loss. Sensorineural hearing loss may be caused by trauma, damage, of physiological abnormalities within the outer ear, middle ear, inner ear or the eighth cranial nerve (vestibulocochlear nerve. The hearing loss associated with noise exposure is commonly referred to as noise induced hearing loss (NIHL) and is prevalent in those who work in loud settings such as factories, use heavy machinery, or use firearms (Martin & Clark, 2019). Another term used to describe NIHL is acoustic trauma which is when acoustics in the environment(s) that surround us may cause trauma to the anatomical structures in the inner ear, causing decrease in physiological function (Martin & Clark, 2019).

Noise induced hearing loss has been studied significantly in humans and canines, but there is less research and understanding of how noise exposure affects the equine auditory system, although similar to human and canine auditory systems in terms of cochlear mechanics and nerve function, as explained later. Mounted shooting as well as mounted patrol have become widely popular in our culture and could be affecting the horses more than we understand. Understanding the effects of the sound environment on equine hearing will allow us to pinpoint if there is a correlation between high amounts of noise exposure and hearing loss.

Literature Review

Equine Auditory System

The normal equine ear has the ability to locate sounds all around and focus on one specific auditory signal and hear sounds from far away. Equines have a similar anatomy of the external, middle, and inner ears as humans. The pinna, external auditory meatus, tympanic membrane, ossicles, cochlea, vestibular system, and cranial nerve pathway are similar to those of other mammalian species. The equine auditory system can hear sounds ranging from 55 to 33,500 Hz with the best sensitivity at 1,000 Hz to 16,000 Hz (Heffner & Heffner, 1983), while humans hear frequencies from 20 to 20,000 Hz. This suggests that humans can detect much higher sounds than horses and further research is needed to determine if horses can hear sounds at a lower decibel level than humans.

Some differences between the human and equine auditory system noted by Blanke, Aupperle, Seeger, Kubick, and Schusser (2014) were additional ridges in equine external auditory meatus that were not present human anatomy. The ceruminous glands in the equine pinna are coiled tubular glands mimicking the appearance of sweat glands. Equines also have a special musculature that allows the ear to rotate 180 degrees to help them locate and funnel sounds. The tensor tympani muscle is larger than in humans and is fan shaped in appearance. The average number of coils for a horse cochlea is 2.25 turns rather than the 2.5 turns present in most humans. Understanding both the similarities and differences between the human and equine acoustic organs provides us with a better understanding of clinical aspects and auditory system capabilities (Blanke et al., 2014). With this understanding, we can identify the main focus and physiological location of a possible hearing loss, as well as set our expectations for response time to the BAER test which is the same as the Auditory Brainstem Response test that is typically completed on babies.

Noise Induced Hearing Loss (NIHL)

Noise induced hearing loss occurs when an individual is exposed to high levels of noise. These sounds can be extremely loud bursts, or loud sounds that the individual has been exposed to over an extended period of time (National Institute on Deafness and Other Communication

Disorders, 2020). The sound damages the structures of the auditory system causing a temporary threshold shift or long-term loss of hearing.

When the hearing loss is considered conductive due to noise exposure, the sound is so damaging that it could rupture the ear drum or damage the ossicles, affecting the outer and middle ear function. However, it is most common for noise induced hearing loss to be sensorineural and damage the sensitivity of outer hair cells. Noise induced hearing loss can be short term and have a temporary threshold shift (Strain, 2015), or it can result in long-term damage even if the patient does not realize it; the hair cells will never “heal” once they have been affected. Many human patients with NIHL commonly present with tinnitus (National Institute on Deafness and Other Communication Disorders, 2020).

Ear physiology in NIHL

As described above, NIHL causes damage to the hair cells and other structures in the inner ear that vibrate in response to sound waves at specific frequencies (Schneider, 2019) to all species. When a sound is presented, the tympanic membrane vibrates, moving the three ossicles (malleus, incus, and stapes); the footplate of the stapes pushes on the oval window transducing the mechanical energy into electro-chemical energy in the cochlea. The cochlea has tonotopic (frequency) organization with the high frequencies coded at the basal end and low frequencies on the apical end. Movement of the endolymph within the scala media creates a traveling wave alone the basilar membrane until it reaches a maximum displacement at a given frequency, and then the wave quickly dies (National Institute on Deafness and Other Communication Disorders, 2020).

When it comes to noise induced hearing loss, there is typically little damage on the apical portion (low frequency area of the cochlea) but the outer hair cells in the organ of corti may be severely damaged more towards the base (high frequencies). Looking the cochleas of rats after noise exposure, Chen and Fechter (2003) found that hair cells were not completely dead; however, their sensitivity was much lower compared to those who were not exposed (Chen & Fechter, 2003). There is also permanent damage to the cochlear neurons that adds to the increase in hearing thresholds in patients (Kurabi et al., 2017). In previous research focusing on humans, a swelling of the afferent nerve endings underneath the inner hair cells was found, which can suggest an overproduction of glutamate from overstimulated hair cells. It has also been reported that the excitotoxity that the hair cells produced when exposed to loud sounds is irreversible, which can eventually lead to NIHL (Kurabi et al., 2017). There isn't any direct research into how loud sounds affect the equine auditory system but based on previous knowledge on the inner ear we can assume the same damage is happening.

NIHL is correlated with exposure to a sudden extremely loud sound, or constant exposure to a loud sound (NIOSH). In general working in environments where the sound is over 85 dB, they can have a total of 8 hours sound exposure without causing a temporary or permanent threshold shift. The National Institute for Occupational Safety and Health (NIOSH), a program that is part of the CDC, determines safe levels of exposure for an individual; they claim a person can be exposed to 85 dB for 8 hours for total daily sound exposure. By using a 3-dB exchange rate, they can determine how much exposure is determined safe. NIOSH exposure parameters are as follows: 85 dB SPL for 8 hours, 88 dB SPL for 4 hours, 91 dB SPL for 2 hours, 94 dB SPL for 1 hour, etc. Exceeding these sound exposure recommendations often is why NIHL is so common (Centers for Disease Control and Prevention, 2020). However, loud bursts such as firearms reach well over 100 dB and it is important to realize how even one sound can be damaging (Schneider et al., 2019).

Firearm Noise Levels

Firearms can release large booms of sound, damaging mammalian auditory system. NIOSH considers safe levels of daily total exposure for humans to be: 85 dB SPL for 8 hours, 88 dB SPL for 4 hours, 91 dB SPL for 2 hours, 94 dB SPL for 1 hour, etc. (CDC, 2020). A firearm's peak sound pressure level can range from 140 dB SPL to 175 dB SPL. The opposite ear (away from the barrel) is often exposed to levels as high as 155 dB SPL. That is enough sound to damage the human auditory system (Murphy et al., 2012).

Auditory Brainstem Response

The brainstem auditory evoked response (BAER) tests for hearing loss by measuring the evoked potential after an acoustic stimulus has been applied. The stimulus can be delivered by air conduction as pulses or tone bursts or by bone conduction through the mastoid. It is important to be aware that when using the BAER test there must be at least 3 electrodes used for recording, grounding, and reference. When testing animals, these electrodes are small-gauge subcutaneous needle electrodes placed on the top of the head, by the tragus, and either contralateral to the ear or over the dorsal spinous process (King & Sininger, 1992). By providing an acoustic stimulus with intensity anywhere from 90 to 120 dB SPL, the electrodes will record neurologic activity (Oken & Phillips, 2009). A waveform is produced by the central auditory pathway that generally contains seven peaks labeled waves I through VII, but in the clinical setting, we label and focus on waves I, III, and V. Waves I, III, and V are going to be the most robust and reliable when it comes to hearing status estimations. Wave V typically is the largest and the last wave that is present. We typically see a series of five peaks that are identified during the first 10 milliseconds after the stimulus is presented (Webb, 2009). By stimulating the ear with an external signal, clicks in this case, we are going to be stimulating the entire auditory system both peripheral and central. The central auditory system is going to show us the neural responses of the auditory system starting at the auditory nerve all the way up to the lateral lemniscus.

Waves of the Brainstem Auditory Evoked Response Test for Humans

When testing an individual with a normal audiogram, we will be able to see and label the five main peaks. We are then able to identify the general anatomical location of each wave. Some waves can be generated by one region, or one wave can be generated by more than one anatomical location (Møller & Jannetta, 1982; Møller & Jannetta, 1985; Møller et al., 1995).

The first wave (wave I) can be seen as early as 1 to 2 milliseconds after the onset of the auditory stimulation and has been identified as being generated at the distal portion of the eighth nerve. The afferent nerve fibers traveling away from the cochlea and entering the internal auditory meatus are the main generators of wave I. The peak of wave I drops off into a trough after the signal has passed through the internal auditory meatus (Oken & Phillips, 2009; Møller & Jannetta, 1982). Wave II is also generated by the eighth nerve but from the proximal portion of the nerve, close to the brainstem near the junction of the pons and the medulla. Sometimes this signal is not picked up in BAER testing due to a shorter length of the nerve (Oken & Phillips, 2009; Møller & Jannetta, 1982; Møller & Jannetta, 1985; Møller et al., 1995).Wave III is commonly associated with the pons near the superior olivary complex. There may be noticeable changes in the wave if there is an abnormality or lesion within the superior olivary complex (Britt & Rossi, 1980; Oken & Phillips, 2009).The generator site that creates the peaks for wave V is the lateral lemniscus or inferior colliculus. This wave is the most prominent of them all and is the best at indicating an abnormality if delayed or not present at 4.71 ±0.24 ms for a horse (Rolf et al., 1987). Waves VI and VII, although part of the BAER response, are harder to pinpoint generators for. These are less “important” when looking at the evoked potentials for clinical use (Møller & Jannetta, 1982).

BAER Testing with Horses

When looking over the methods for evaluating the auditory systems of animals, one that seems to be the most effective is the BAER test. Best practice for BAER testing on horses is still being determined. In early studies, the active electrode was placed on the forehead, the reference electrode was placed at the bottom of the ear canal, and the ground electrode was placed on the outside of the pinna of the contralateral ear. One ear at a time was tested with a bandpass filter of 300 to 8000 Hz. The auditory stimulus was presented at 55 clicks per second in 10 dB increments ranging from 10 dB HL to 90 dB HL until they had the ability to identify the thresholds (Marshall, 1985).

In 1990, Mayhew and Washbourne used a different method of testing with BAER testing on horses. They used moderately sedated horses and placed the electrodes on the vertex and zygomatic processes on both sides of the head. By using the sedation, they were able to ensure that the results obtained were from the acoustic stimulation. They used intensities ranging from 30 dB HL to 100 dB HL. Using a higher sampling rate of clicks, they were also able to obtain larger datasets. They found that it helps to mask the non-test ear with at least 10 dB of white noise to ensure they are getting information from only one ear (Mayhew & Washbourne, 1990). BAER testing with horses no longer need sedation as long as the horse is calm and using 108 dB nHL is used to determine the status of the central auditory system before trying to find the estimated thresholds.

Hearing Loss in Horses

Looking at BAER testing results, there has been little evidence that gender or breed, besides the American Paint Horse, influences test results (Magdesian et al., 2009). Some research shows a correlation of hearing loss with genetic markers and/or age.

Older horses show a decline in threshold and partial deafness compared to younger horses. Aleman et al. (2014) found that of 76 horses, 57 showed declines compared to normal hearing levels and those horses were 17 to 22 years of age. They were able to determine that the most common bilateral auditory loss was sensorineural, but the causes could have been congenital, thyrohyoid osteoarthropathy, multifocal brain disease, and/or otitis media or interna (Aleman et al., 2014). However, Melvin (2018) found that there were no differences in thresholds, latencies, or amplitudes in BAER results of older and younger horses. There were some “insignificant” differences between the groups that could have had hearing loss due to aging or other factors such as noise exposure or use of medications that are toxic to the ear.

Another cause for abnormal BAER results stems from congenital factors. White pigmentation and an overall lack of pigmentation has been correlated to underdeveloped organs. These organs can be intestinal, vital, or auditory organs (Strain, 2015). The American Paint Horse, if not marked with lethal white syndrome, is more prone to underdeveloped auditory systems, which can lead to unilateral or bilateral hearing loss (Harland et al., 2006)

How loud sounds affect working animals

There hasn’t been any research this far analyzing how loud sounds affect horses but there has been research looking at dogs who have been exposed to high levels of sound such as firearm noise demonstrate bilateral sensorineural hearing loss. In one study of three dogs, one dog never had the ability to regain his hearing, and another was able to regain hearing after doses of

Vitamin B, E, and N-acetyl-cystine, the third dog was lost before treatment. The three dogs tested worked in loud occupation settings (Schneider et al., 2019). The dog in Case 1 worked as a sniffer for the Metropolitan Police in the United Kingdom. When training began, the dog had no hearing abnormalities and was considered normal, but later had to be woken by physical stimulus as anything verbal or acoustic was not working. The BAER results determined that the bilateral threshold was at 80 dB HL (Schneider et al., 2019). Case 2 was a working hunting dog (otherwise called a gundog) with exposure to at least 40 shots a year. In this case, the owner claimed that the dog was less and less responsive when it came to hearing a whistle. Although there were no obtained BAER results due to a hardware crash, with no evidence of abnormalities either physical or neurogenic, they were able to conclude that the dog had some form of hearing loss (Schneider et al., 2019). The Case 3 dog was a working police dog that would often be exposed to exercises where the firearm was fired five times near the right ear with an estimated noise level at 140 dB SPL. The was an absence of waveforms in the right ear during the BAER examination, and it was concluded that there was a “unilateral NIHL” (Schneider et al., 2019). Previous data from humans shows that wave morphology can indicate a possible cochlear loss (Watson 1999) and hearing can be considered abnormal if the morphology is poor.

This study, although not large was able to identify that NIHL is likely to be under documented in working canines. The issue is much larger than what the veterinary community believes and can impact the behavior of a canine in the field. As dogs and horses are alike and not able to tell us that they cannot hear, it is the job of the owner to look for the signs for hearing loss if their canine or horse such as decreased responsiveness to environmental stimulus (Schneider et al., 2019).

While there is an understanding of the effects of noise on the human and canine auditory systems, there is little information about effects on equine hearing. We have research to show the anatomical and physiological similarities between horses and other mammals, but there is still little we understand about the effects that high levels of noise exposure such as firearms have on horses. With shooting sports and working horses, it is important to understand how noise can affect horses in the short and long term. By specifically looking at horses, we may be able to add knowledge about noise induced hearing loss in equines and determine if intervention is needed.

Methodology

Participants

This project was approved by the Institutional Animal Care and Use Committee (IACUC) before recruitment and testing were completed to obtain BAER examination results from a total of 12 equines from local barns in Greeley, CO and Denver, CO. Five of the horses were grouped into a non-exposed group (C1-C5); all had zero exposure to firearms with ages ranging from 10 years to 18.8 years. The remaining seven horses were grouped into the exposed group (E1-E7), ages ranging from 11.4 years to 18.8 years (Table 1).

Table 1

Subject characteristics – any notable physical characteristics

Subject	Physical Factors	Age (years)	Exposure Time (years)
E1	Roan, grade, gelding	17.8	6
E2	Mustang, black, 4 white stockings, gelding	18.8	10
E3	Palomino, gelding, no white markings	11.6	4
E4	Bay, grade, gelding	13.8	2
E5	Black and white paint with blue eye, mare, APHA	11.4	5
E6	Bald face sorrel, grade, gelding	14.8	3
E7	Grey, AQHA, mare	12.5	4
C1	Sorrel, AQHA, gelding	11.8	None
C2	Flea-bitten grey, Arabian, gelding	18.8	None
C3	Sorrel, AQHA, mare, moon blindness in left eye	17.6	None
C4	Buckskin, AQHA, gelding	18.6	None
C5	Black and white paint, grade, mare	11.4	None

To be considered exposed, horses must have been repeatedly exposed to firearms over a period of at least two years. The horses were of varying breeds and backgrounds, as breed was not a specific factor when considering the qualifications for this research. Some of the noteworthy abnormalities within the participant pool include: one horse in the control group was diagnosed with moon blindness four years prior to our study (2017), and one horse within the exposed group was a black and white paint mare with one brown eye and one blue eye. Each horse owner signed a consent form that described the procedure and the purpose of the study. All testing was done on the owner's premises or that of their contracted boarding facility. Horses were held by the owners in a rope halter and lead rope, either outside or in an indoor arena. All horse owners were given a pair of Cashel foam earplugs before testing to practice inserting and removing the earplug, both ensuring comfort and desensitizing the horse to having an object in the ear when it came time to test. It is also important to note that horses that were exposed did not wear the Cashel earplugs during the exposure events.

Preparation of Equines

On the day of testing, all horses had a thin film of lidocaine topical cream (lidocaine 2.5%/prilocaine 2.5%) applied to the site of electrode placement (side of neck, middle of forehead, and above C2). Rhythmlink disposable bent subdermal needle electrodes with a 13 mm length and 0.4 mm diameter were placed in the middle of the forehead, on the side of the neck, and above C2 under the mane. The lidocaine was rubbed in and absorbed before placing electrodes, which were then inserted while standing at the right shoulder of the horse. By pinching the skin and pushing, the electrodes were inserted with the opposite hand. A check for correct placement was conducted by running the index finger over the placed electrode to make sure the needle was able to be felt under the skin. Vet wrap was placed around the horse's neck in between placement of the ground and reference electrodes to ensure they remained in place if the horse were to move (Figure 1).

Figure 1

Horse prepared for BAER testing and ear plug

After placement of the electrodes, standing at a diagonal between the horse's nose and shoulder, the research team placed the Cashel earplug, with the ER2 insert earphone in the middle, into the ear. As soon as the earplug was correctly placed, the clinician put vet wrap around the pinna to ensure no movement of the earplug.

Data Collection

The Intelligent Hearing Systems USB box with Smart EP software version 5.42 was connected to an HP laptop computer with a Windows 10 operating system. Electrode impedance was checked and monitored with a 2-channel Opti-Amp power transmitter prior to each test and impedance was kept between 1 and 3 kΩ at the electrode sites. If the electrode impedance was not within acceptable parameters, we adjusted the electrode until we obtained the desired impedance. By using a 100-microsecond broadband click with a 12,000 Hz bandwidth power spectrum, we elicited a response. A click stimulus produced by the computer was directed into the Cashel earplug to the ear (Figure 2). The click stimulus was presented at a rate of 21.1 clicks per second using a rarefaction polarity. The stimulus intensity for all horses was 118 dB peSPL in the right ear. One horse from each group was tested for hearing threshold, which was picked at random and based on behavior during initial testing, starting at 118 dB peSPL decreasing in 10 dB increments until wave V was no longer visible. All horses had least two recordings at each intensity were collected in a 12 ms window to ensure reliable results.

Absolute latencies of waves I, III, and V, and interpeak intervals of I-III, III-V and I-V were measured at 108 dB SPL. Wave V peaks were identified and agreed upon between the researcher and one professional experienced in BAER waveform interpretation. The latency measurements for each participant were averaged (Table 2) and means were compared between groups using the Mann-Whitney U two-tailed nonparametric statistical test to try to determine if there was any statistical difference between the two groups. Waveform morphology was also rated such as good, fair, poor by two different researchers and then compared and categorized by visibility of waves and overall repeatability between wave forms. Good morphology being clear waves and good repeatability, fair morphology being presence of the waves with repeatability but not as clear as good, and poor morphology indicated absence of one or more waves and no repeatability between test trials.

Results

There was no statistical difference between the exposed and the nonexposed group for the mean absolute latency of wave V ($N = 12$, $p = .255$). The latencies obtained for all horses are in agreement with those reported by Aleman et al. (2014) indicating good result reliability.

Table 2

Mean BAER latencies for each subject and each group.

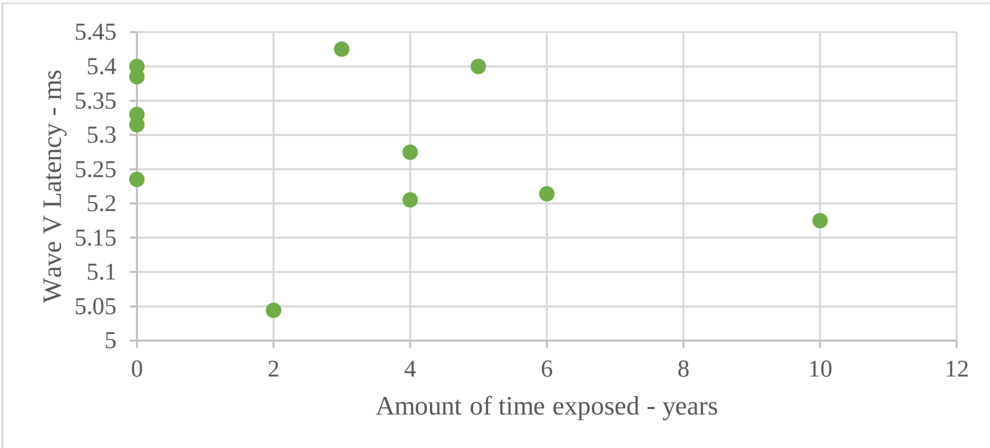
Participant	Wave I	Wave II	Wave III	Wave IV	Wave V
C1	1.815	2.3	3.2	4.315	5.235
C2	1.49	2.38	3.56	4.09	5.33
C3			3.59	4.35	5.385
C4	0.95		3.285	4.265	5.315
C5	1.925	2.435	3.305	4.59	5.4
C1-5 mean	1.545	2.372	3.388	4.322	5.33
E1				4.5	5.215
E2				4.345	5.175
E3	1.11		3.34	4.165	5.275
E4				4.055	5.044
E5	1.775		3.71		5.4
E6		2.41	3.49	4.36	5.425
E7		2.41	3.39	4.055	5.205
E1-7 mean	1.436	2.41	3.483	4.257	5.248

Note: Subjects C1-C5 were in the nonexposed group; subjects E1-E7 were horses exposed to firearm noise.

After seeing no differences in the averages, we investigated determining if we were able to see any differences in the presence of wave V by calculating the standard deviation (Table 5) and range (Table 6). Once again, there were no statistical differences between the standard deviation and range of wave V between the control and exposed category.

Figure 4

Exposure Time vs. Wave V Latency shows a scatterplot of the wave V latencies for both groups. There were no significant trends that showed us any difference in the wave V absolute latencies at 108 dB nHL.



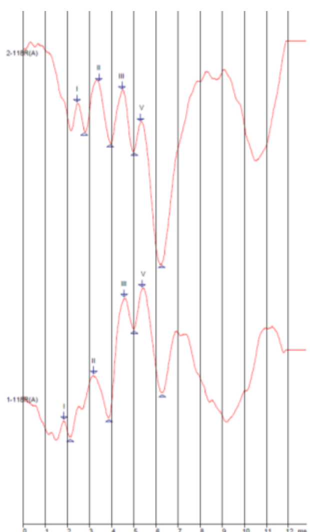
We also analyzed the overall morphology of the BAER waveforms. The control group of horses were considered to have good wave morphology and the exposed horses ranged from fair-to-good morphology to poor morphology (Table 3) . Figure 3 represents a good waveform, another showing poor waveform, and shows extremely poor wave morphology, taken from a medicine cap, blue eyed, paint horse in 2020 indicating no/very minimal hearing in both ears (not a part of this research). Red waveforms indicate the right ears and the blue waveforms indicate left ear responses.

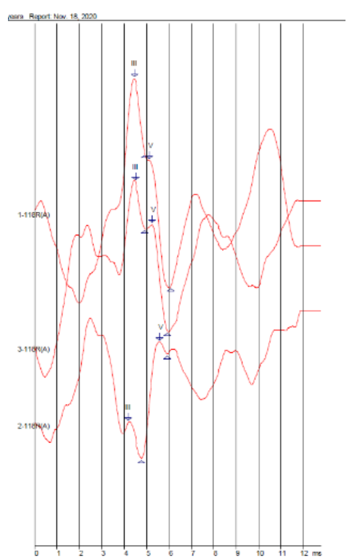
Table 3

Morphology quality for each set of BAER waveforms.

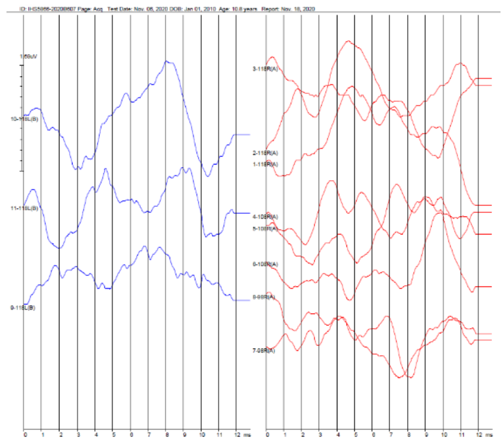
Subject ID	Outcome	Testing Group
C1	Good Morphology	No exposure
C2	Good Morphology	No exposure
C3	Good Morphology	No exposure
C4	Good Morphology	No exposure
C5	Good Morphology	No exposure
E1	Poor Morphology	6 years
E2	Poor Morphology	10 years
E3	Fair to Good Morphology	4 years
E4	Fair Morphology	2 years
E5	Fair Morphology	5 years
E6	Fair Morphology	3 years
E7	Poor Morphology	4 years

Figure 3
Good waveform – C4





Poor/inconsistent wave form – E2



Extremely poor wave morphology – peaks were not labeled due to poor reliability and lack of wave presence.

Discussion

There was no significant difference between the interpeak or absolute latencies when comparing the two test groups, however there was a significant difference in the morphology indicated some change in the auditory system function. These results are consistent with research completed on other species with noise exposure. We cannot compare this research to others looking at horses and noise exposure since there is no other research.

The present study did not control for breed, medical history, or age. Future studies might evaluate horses using the BAER with the following considerations. Adding breed restrictions to eliminate breeds such as the American Paint Horse who may have hearing loss due to genetic abnormalities. Also, by expanding the test group size we can increase the test reliability, and by completing BAER evaluations on horses before exposure and tracking any changes over time following noise exposure.

Our results indicated that exposure to firearms affects equine hearing. Although there were no statistical differences in wave latencies between groups, it was determined that wave I was less likely to be present in the group of horses exposed to firearm noise. With the presence of a cochlear hearing loss cause by noise exposure we would expect the latencies to be later as it is taking longer to stimulate the auditory nerve. In humans we see latency differences and use them to identify hearing loss when able to compare them to normative data and interaural differences. In addition, the morphology of the waveforms from the two groups displayed noticeable differences. Specifically, the morphology of the waveforms from the horses exposed to noise showed reduced repeatability and missing peaks, especially wave I. Visual analysis of two different researchers, the waveforms indicated that all five of the nonexposed horses had good waveform morphology, while all seven of the exposed horses had fair to poor morphology. It is important to note that analyzing morphology is subjective so using the analysis of two researchers who have not collaborated previously we were able to get a more reliable analysis. Good morphology was defined as the presence of five peaks on repeatable waveforms. Poor morphology was defined as absence of one or more peaks with poor repeatability.

The goal of this thesis was to evaluate if there is a need for continued research on equine auditory function when exposed to firearms. Based on previous studies on humans and our results suggesting differences in the presence of wave I and the change in morphology between the two test groups, there is a need to re-evaluate this concept and seriously consider that firearms harm horses auditory systems. This study is motivated and implemented BAER testing for the first time finding qualitative differences in wave morphology for a group of exposed to firearm noise and a control group. Although there were no qualitative differences found in wave V absolute latencies in future research the presence, latency time, and amplitude should still be considered to determine the effects of noise exposure. Such testing could be used to monitor hearing status in animals that are participating in events with firearms such as equine shooting sports and work on implementing a program on use of hearing protection for these animals.

References

Aleman, M., Holliday, T.A., Nieto, J.E., & Williams, D.C. (2014). Brainstem auditory evoked responses in an equine patient population: Part I – Adult horses. *Journal of Veterinary Internal Medicine*, *28*, 1310-1317. doi: 10.1111/jvim.12379

Blanke, A., Aupperle, H., Seeger, J., Kubick, C., & Schusser, G.F. (2014). Histological study of the external, middle, and inner ear of horses. *Anatomia Histologia Embryologia*, 1-8. doi: 10.1111/ahe.12151

Britt, R. H., & Rossi, G. T. (1980, April 1). Neural generators of brainstem auditory-evoked responses. *The Journal of the Acoustical Society of America*, doi: 10.1121/1.2018464

Center of Disease Control and Prevention - Noise and Hearing Loss Prevention - National Institute for Occupational Safety and Health (2018, February 6). Retrieved from https://www.cdc.gov/niosh/topics/noise/default.html

Chen, G.-D., & Fechter, L. D. (2003). The relationship between noise-induced hearing loss and hair cell loss in rats. Retrieved from: https://www.sciencedirect.com/science/article/pii/S037859550200802X

Harland, M. M., Stewart, A. J., Marshall, A. E., & Belknap, E. B. (2006). Diagnosis of deafness in a horse by brainstem auditory evoked potential. *The Canadian Veterinary Journal*, *47*(2), 151.

Heffner, R.S., & Heffner H.E. (1983). Hearing in large mammals: Horses (Equus caballus) and cattle (Bos taurus). *Behavioral Neuroscience, 97*, 299-309. Retrieved from http://psycnet.apa.org/journals/bne/

King, A.J., & Sininger, Y.S. (1992). Electrode configuration for auditory brainstem response audiometry. *American Journal of Audiology*, *1*, 63-67. doi: 10.1044/1059 0889.0102.63

Kurabi, A., Keithley, E. M., Housley, G. D., Ryan, A. F., & Wong, A. C. Y. (2017). Cellular mechanisms of noise-induced hearing loss. *Hearing research*, *349*, 129-137.

Magdesian, K.G., Williams, D.C., Aleman, M., LeCouteur, R.A., & Madigan, J.E. (2009). Evaluation of deafness in American paint horses by phenotype, brainstem auditory evoked responses, and endothelin receptor B genotype. *Journal of the American Veterinary Medical Association*, *235*, 1204-1211. doi: 10.2460/javma.235.10.1204

Marshall, A.E. (1985). Brain stem auditory-evoked response in the nonanesthetized horse and pony. *American Journal of Veterinary Research*, *46*, 1445-1450. Retrieved from http://avmajournals.avma.org/loi/ajvr

Martin, F. N., & Clark, J. G. (2019). Introduction to audiology (13th ed.) (pp. 307-309) NY: Pearson.

Mayhew, I.G. & Washbourne, J.R. (1990). A method of assessing auditory and brainstem function in horses. *British Veterinary Journal*, *146*, 509-518. doi: 10.1016/0007 1935(90)90054-7

Melvin, B. (2018). The brainstem auditory evoked response in old versus young horses [Doctoral capstone, University of Northern Colorado]. Digital UNC. https://digscholarship.unco.edu/capstones/40/

Møller, A.R. & Jannetta, P.J. (1982). Evoked potentials from the inferior colliculus in man. *Electroencephalography and Clinical Neurophysiology*, *53*, 612-620. doi: 10.1016/0013-4694(82)90137-7

Møller, A.R., & Jannetta, P.J. (1985). Neural generators of the auditory brain stem response. In J.T. Jacobsen (Ed.), The auditory brain stem response. San Diego, CA: College Hill Press, Inc.

Møller, A.R., Jho, H.D., Yokota, M., & Jannetta, P.J. (1995). Contribution from crossed and uncrossed brainstem structures to the brainstem auditory evoked potentials: A study in humans. *Laryngoscope*, *92*, 596-605. doi: 10.1288/00005537

Murphy, W. J., Flamme, G. A., Zechmann, E. L., Dektas, C., Meinke, D. K., Stewart, M., ... & Finan, D. S. (2012). Noise exposure profiles for small-caliber firearms from 1.5 to 6 meters. *The Journal of the Acoustical Society of America*, *132*(3), 1905-1905.

National Institute on Deafness and Other Communication Disorders. (2014). Noise induced hearing loss. U.S. Department of Health and Human Services, National Institutes of Health. Retrieved from https://www.nidcd.nih.gov/health/noise-induced-hearing-loss

Oken, B.S, & Phillips, T.S. (2009). Evoked Potentials: Clinical Retrieved from Encyclopedia of Neuroscience (pp. 19-28)

Rolf, S. L., Reed, S. M., Melnick, W., & Andrews, F. M. (1987). Auditory brain stem response testing in anesthetized horses. *American Journal of Veterinary Research*, *48*(6), 910-914.

Schneider, D. C., Foss, K. D., Risio, L. D., Hague, D. W., Mitek, A. E., & McMichael, M. (2019). Noise-Induced Hearing Loss in 3 Working Dogs. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S1938973619300996

Strain G. M. (2015). The Genetics of Deafness in Domestic Animals. *Frontiers in veterinary science*, *2*, 29. https://doi.org/10.3389/fvets.2015.00029

Watson, D. R. (1999). A study of the effects of cochlear loss on the auditory brainstem response (ABR) specificity and false positive rate in retrocochlear assessment. *Audiology*, *38*(3), 155-164.

Webb, A. A. (2009). Brainstem auditory evoked response (BAER) testing in animals. The *Canadian Veterinary Journal*, *50*(3), 313.