Reindeer (*Rangifer tarandus tarandus*) perception of noise from power lines

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Abstract: There has been concern about possible effects of noise from power lines on reindeer (*Rangifer tarandus tarandus*) behaviour. Based on recent establishment of the reindeer audiogram and measurements of corona noise from two power lines of 300 kV and 420 kV, we found that reindeer are able to hear noise from power lines at frequencies above 250 Hz. A comparison with the human audiogram shows that humans are better able to perceive noise from power lines than reindeer, at least at the lowest frequencies. By simple comparisons of this kind, the perception of different types of sound by reindeer can be determined. Possible noise disturbances from human activities and constructions can be minimised if the intensity can be reduced for frequencies in the best hearing range of reindeer.

Key words: audiogram, background noise, corona noise, hearing range, hearing threshold, noise attenuation.

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Introduction

Several studies have focused on the effects of noise on wildlife in general (Comber & Zaffanella, 1975; Busnel & Fletcher, 1978; Lee & Griffith, 1978; Lee & Reiner, 1983; Larkin, 1996). Activities with sudden high intensity noise have been shown to behaviourally or physiologically affect reindeer and caribou (*Rangifer tarandus*) (Harrington & Veitch, 1991; Berntsen, 1996; Bradshaw *et al.*, 1997; Maier *et al.*, 1998). In addition, it has been hypothesised that continuous low-intensity noise, like noise caused by electrical discharges from power lines in moist weather (corona), may disturb reindeer as well (Busnel & Fletcher, 1978; Reimers *et al.*, 2000). This hypothesis can be evaluated using knowledge about the hearing ability of *Rangifer*, recently published by Flydal *et al.* (2001). Here, we present measurements of corona-noise from power lines together with an assessment of the perceptibility of such noise by reindeer, based on the established audiogram.

Material and methods

Measurements of noise from high voltage transmission lines were performed at a 300 kV and a 420 kV line in Nordmarka, north of Oslo, Norway. Measurements were done during rainy weather at temperatures of 0 - 4 °C, weather conditions with high levels of corona noise (Engel & Wszolek, 1996). The sound pressure level (dB re. 20 μPa) was measured with a Brüel & Kjær 4155 microphone connected by a 5 m cable to a Brüel & Kjær 2231 sound level meter and a Brüel & Kjær 1624 octave filter with centre frequencies from 63 Hz to 16 kHz. The microphone was calibrated with a Brüel & Kjær 4231 pistonphone.

The noise recordings were performed directly underneath the power lines by mounting the microphone on a tripod one meter above ground and directing it upwards towards the source of corona noise. The mean noise level in 10 s time periods was measured for each octave, with a 10 s break between each octave setting. Thus, the 9 octave bands were measured in about 170 s. Background noise measurements were performed about 400 m away from the power lines at sites with similar background noise conditions. These measurements were performed about 10 minutes after the measurements from the power lines. If the weather conditions changed during this 10 min period, all the recordings were repeated at both sites to assure the same noise conditions.

The reindeer's ability to perceive the corona noise was evaluated based on the hearing threshold for pure tones (Flydal *et al.*, 2001); as a reference, the same evaluation was done for humans. Most noises are not stable in intensity over wide frequency bands but vary in amplitude, and the hearing threshold for such noises measured over a continuous spectrum have been reported to be similar to pure tones (Kinsler & Frey, 1962). Since corona noise from power lines does not have a stable intensity over the one-octave frequency bands (Engel & Wszolek, 1996), the hearing threshold for pure tones could be used as an estimate of the hearing threshold for the noise.

Estimates of the critical ratio (i.e. the ratio of the level of a tone signal at the masked threshold for detection to the spectrum level of the noise masker) for humans (Hawkins & Stevens, 1950) and for cats (*Felis sylvestris catus*) (Costalupes, 1983), suggest that corona noise may be detectable at intensities lower than the background noise. However, the corona noise will not be a dominant sound source in the environment at such a low intensity and thus unlikely to be disturbing (Larkin, 1996). Therefore, we defined the maximum distance of perceptibility as the distance where the corona noise intensity at an octave band was equal to the background noise at the same octave band. The maximum distance of perceptibility was calculated based on theoretical attenuation with distance in air of sound from a line source. The attenuation is due to spherical spreading loss and a variable attenuation factor (depending on frequency, humidity and temperature) from heat conduction and viscosity, and vibration relaxation of oxygen molecules in air (Beranek, 1988). Calculations of the maximum distance of perceptibility (d) were based on attenuation characteristics of sound in air at 2 °C and 100% relative humidity for the different octave frequencies from 63 Hz to 8 kHz (Beranek, 1988; Solberg, 2001), using the following equation for attenuation (A) in dB by distance (d):

$$A(d) = -20 \times \log(d/15) - a_{fr} \times d$$

where 15 m is the reference distance where we did the noise recordings and a_{fr} is the attenuation factor in air for the frequency.

Results and discussion

The corona noise intensity from the 300 kV and 420 kV power lines were higher than the background noise intensity for all frequency bands except at 63 Hz for the 420 kV line (Table 1). For the 300 kV

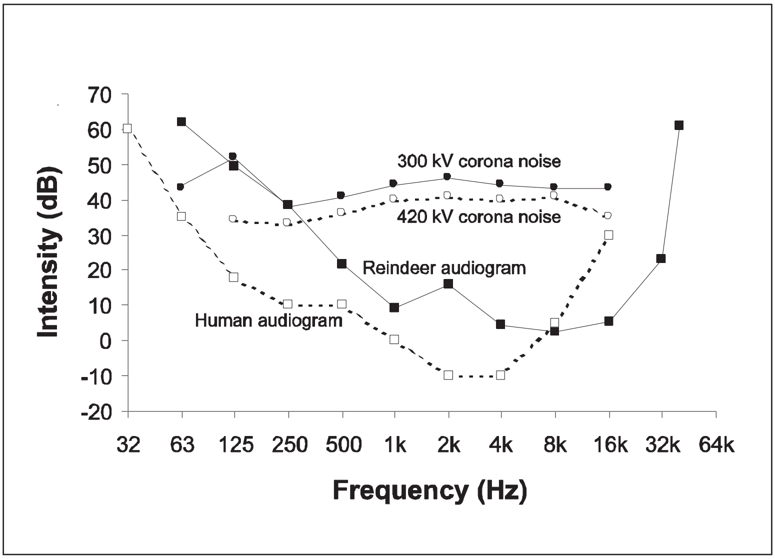

Fig. 1. Audiogram of reindeer (Flydal *et al.*, 2001) and man (Fay, 1988), and measurements of noise from 300 kV and 420 kV power lines measured directly underneath the power lines (see methods).

Table 1. Measurements of background noise and corona noise from 300 kV and 420 kV power lines in rainy weather at 0 - 4 $^{\circ}$C. Measured in octave bands 1 m above ground and about 15 m from the lines.

Centre frequency (band width) (Hz)	300 kV Corona Noise (dB)	300 kV Background noise (dB)	420 kV Corona Noise (dB)	420 kV Background noise (dB)
63 (44.7 - 89.1)	43	37	37	42
125 (89.1 - 178)	52	28	34	32
250 (178 - 355)	38	27	33	29
500 (355 - 708)	41	27	36	33
1000 (708 - 1410)	44	32	40	34
2000 (1410 - 2820)	46	35	41	28
4000 (2820 - 5620)	44	34	40	23
8000 (5620 - 11200)	43	30	41	22
16000 (11200 - 22400)	43	25	35	17

line, the highest noise intensity was at 125 Hz, with 52 dB (background noise, 28 dB). At the other frequencies, the noise intensity varied between 38 and 46 dB, 6 to 18 dB above the background noise. For the 420 kV line, there was no marked noise intensity peak around 125 Hz, but the corona noise was highly dominant over the background noise at frequencies from 1 kHz to 16 kHz, with a maximum of 41 dB, 19 dB higher than the background noise, at 8 kHz.

At lower frequencies (63 Hz, 125 Hz and 250 Hz), the noise intensity was lower, or at about the same level as the hearing threshold of reindeer. At higher frequencies (500 Hz to 16 kHz), the noise was well above the hearing threshold of reindeer (Flydal *et al.*, 2001) (Fig. 1). The human auditory threshold (Fay, 1988), on the other hand, was far below the corona noise for all frequencies from 125 Hz to 8 kHz (Fig. 1). At 16 kHz, the reindeer hearing threshold was about 35 dB below the noise intensity, whereas the threshold of humans was only about 10 dB below. In general, humans have a better perceptibility than reindeer for corona noise at frequencies below 500 Hz, but a poorer ability above 8 kHz.

The subjective characteristic of a sound, commonly known as loudness, increases with increasing sound intensity above the hearing threshold, although the increase in loudness is not equally related to the increase in intensity for all frequencies. At frequencies with high hearing thresholds, the increase in loudness is higher for the same increase in intensity than for frequencies with lower hearing thresholds, until a high intensity level (>80 dB) is reached where the loudness is similar for all frequencies (Kinsler & Frey, 1962). The intensity level of corona noise is relatively low (40 to 50 dB) for all frequencies from 63 Hz to 16 kHz, therefore, humans may perceive stimuli from corona noise as louder than reindeer, especially at the lowest frequencies where humans have lower hearing thresholds.

Estimates of the maximum distance of perceptibility showed a maximum for reindeer of 74 m at 500 Hz for the 300 kV line, and a maximum of 79 m at 4 kHz for the 420 kV line. Due to higher noise from the 300kV line, one would expect a longer reindeer perception distance from this line than from the 420 kV line, specifically in the lower frequency range. The reindeer hearing capacity in this frequency range (below 250 Hz) is however so low that the noise is marginally detectable. For humans, the maximum distance was 236 m at 125 Hz for the 300 kV line, and 79 m at 4 kHz for the 420 kV line. These theoretical estimates show that the better low-frequency hearing in humans means that we are able to hear noise from power lines at longer distances than reindeer in the low-frequency area. This effect is only significant in cases where the corona noise is high in intensity around the second harmonic (100 Hz) of the alternating current, where reindeer have a hearing threshold about 30 dB higher than humans. The hearing threshold for both reindeer and humans is so low at 4 kHz that the perception of the corona noise is only possible when it is higher than the background noise, which occurs at a distance up to 79 m. High levels of background noise around 100 Hz probably masked the 100 Hz hum noise from the 420 kV line measured in our study, but in most cases the hum noise of the second harmonic is reported to be higher in intensity than the more high-frequency corona (Comber & Zaffanella, 1975; Lee & Griffith, 1978; Engel & Wszolek, 1996).

The corona noise to the human ear sounds like a fairly monotonous hissing noise with notable low frequency components. Although reindeer can hear the corona noise from power lines, the noise may not necessarily disturb the animals. A study of enclosed reindeer underneath power lines has not shown specific behavioural responses to increased noise levels from wind turbulence (maximum wind speed at 20-25 m/sec) around the lines (K. Flydal, in prep.);

unfortunately this study was not performed in conditions with moist weather and high corona noise intensity. Studies which have shown behavioural responses and/or short-time increases in heart-rate in *Rangifer* (caribou) have involved human activities with very high noise intensities like petroleum exploration (Bradshaw *et al.*, 1997) and overflights by low-altitude jet-aircrafts and helicopters (Harrington & Veitch, 1991; Berntsen, 1996; Maier *et al.*, 1998). It is likely that sudden noises of high intensity have stronger effects on reindeer than continuous low-intensity noises like corona from power lines (Larkin, 1996).

Knowing the hearing ability of reindeer now makes it possible to assess their ability to perceive different types of noise by simply comparing the reindeer audiogram with noise measurements made at different frequencies. This knowledge could be compared to the specific standards established for noise restriction from industry, traffic etc. in areas of human residence (Beranek, 1988; Solberg, 2001). These standards could be helpful when evaluating possible negative effects of continuous noise from power lines and other human constructions or activities on reindeer. However, it is important to keep in mind that the hearing ability of humans is better than that of reindeer, except at the highest frequencies. Thus, sudden unpredictable noise from human activity may in general have stronger effects than continuous noises, especially because the reindeer may associate the former with danger.

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