The Lombard Effect and the Correlation Between Human and Beluga Auditory Systems

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INTRODUCTION

Studies have shown that ambient noise levels in various bodies of water are rising, and the inhabitants are directly affected by the increased noise. The increasing ambient noise can cause a vocal phenomenon known as the Lombard Vocal Response (Lombard, 1911). The Lombard Vocal Response, also known as the Lombard Effect, is the alteration of vocal intensity in response to ambient auditory conditions; the tendency to speak louder in the presence of background noise to increase comprehension (Scheifele, 2001).

The Lombard Vocal Response was first discovered by Etienne Lombard and published in 1911 in an innovative paper entitled "Le signe de l'elevation de la voix" (Lombard, 1911). A vocalizing animal attempts to maintain a signal-to-noise ratio (SNR) for communication with like species. Under conditions of altered auditory feedback, Lombard's discovery is important in analysis of the SNR and of relations between hearing and acoustic communication (Lane and Tranel 1971). Lombard's discovery opened up many doors into the anatomy of the auditory system, and maybe it will eventually lead to a better understanding of human deafness, and perhaps a possible cure.

Research on bottlenose dolphins by Ridgway (1978) shows broad areas of the cortex giving slow responses to tonal sounds, suggesting that there are differences in the central auditory processing system for marine mammals, and therefore, recognition and assimilation time for these sounds is slower, resulting in a difference in vocal response Scheifele, 2001).

It is known that the vocalization level is increased if there is ambient noise (Lombard, 1911; Ringel and Steer, 1962), and it is believed that the specific changes occur with regard to increases in pitch, amplitude, vowel duration, and spectral tilt (Junqua, 1993). Vocal effort will always increase with an increase in ambient noise, but the degree of elevation varies with the signaler and its belief as to how much of an escalation is required for the receiver to clearly perceive the intended message (Scheifele, 2001). In 1967, Egan conducted an experiment concerning the Lombard Effect, and he concluded that increases in vocal intensity as a result of ambient noise leads to a maximum vocal increase of 12.8 decibels (Egan, 1967).

Studies have shown that noise pollution is a potential danger for marine mammals and to the St. Lawrence beluga (Delphinapterus leucas) in particular. Belugas rely mainly on sound to navigate though their surroundings, find food, and locate mates. Any damage to the beluga auditory system can result in deafness, and potentially death. To determine as to whether or not the beluga are susceptible to noise pollution, researchers can study the auditory and vocal response under increased noise levels. Intensity changes in beluga vocalizations based on environmental noise will show the existence of the Lombard Effect in belugas, and that they are vulnerable to noise pollution. Hidden Markhov “classified” vocalizations were used for acoustical analysis, and the correlation between signals and noise indicate that the Lombard Effect exists in belugas (Scheifele, 2001). With former research indicating that the Lombard Effect Response occurs in humans, a comparison can be made between belugas and humans, concerning their auditory and vocal responses to environmental noise.

HYPOTHESIS

The purpose of this study is to observe the Lombard Effect in humans as an aid in detecting a similar behavior in the Beluga Whale of the St. Lawrence River Estuary. The researcher will try to determine whether:

1. The Lombard Vocal Response occurs in humans.
2. The Lombard Vocal Response occurs in beluga whales.
3. There is a correlation between human and beluga auditory systems.

METHODS

In humans, mammals, and birds, the auditory and vocal production systems work together to maximize communication in noise (Webster and Klumpp, 1962; Kiley, 1972; Lane and Tranel, 1971; Fletcher, 1955). An increase in ambient noise results in an increase in vocalization, and the relationship between ambient noise and vocalization, the Lombard Effect, has already been discovered in humans. The researcher intends to discover whether or not the Lombard Effect exists in beluga whales (Delphinapterus leucas), and if it does, then a comparison can be made between beluga and human auditory systems. Before working with the beluga whales, the researcher intends to substantiate the existence of the Lombard Effect in humans.

There will be five human volunteers who will participate in the determination of the existence of the Lombard Effect in humans. Each person will be pre-tested to determine his or her hearing threshold. In an audiology test booth, each subject will have to read sentences from a set of sentence cards in two trials (Fig. 1).

Let’s Get a Cupful of Coffee.
You’ll Get Fat Eating Candy.
I’ll Take Milk in My Coffee.

Figure 1. Sentences That the Human Subjects Read

The first trial will be the control trial, without any ambient noise. The second trial will be the variable trial, during which the subject will have to read the same sentences while being exposed to noise through earphones. The noise levels will be 40, 30, 50, 60, 50, 40, and 30 decibels. Each noise will be delivered to the subject for a one minute interval. The voice level will be recorded onto time-locked digital audiotapes for analysis. Each subject will read three times under each noise level.

Recordings of beluga vocalization were taken in July and August at various sites at 7:00am, 10:00am, and 2:00pm. Approximately 230 hours of recording were used for this experiment. Recordings were made from the *R/V BLEUVET* of the Centre d’Interpretation des Mammifers Marins (CIMM) near the shoreline of the Saguenay River tributary and St. Lawrence Seaway. Recordings were made with an International Transducer Corporation Model ITC-1042 omnidirectional hydrophone with pre-amplifier (frequency response flat +/- 3dB from 20 Hz to 40 kHz). Recordings were made on a Sony TCD-D8 digital audio (DAT) tape recorder with 48 kHz sampling frequency and 16-Bit linear quantization. The TCD-D8 recorder had a flat frequency response from 20 Hz to 20 kHz. The digital recordings were previewed on a PC using both PRAAT 4.1

speech analysis program (Boersma and Weenink, 2003) for spectrographic analysis and ATSpec Pro spectrum analysis software (Taquis Corporation) for power spectra. A sampling rate of 50-80 kHz was used (vocalization dependent) and an FFT size of 2048 points was used for all signals.

The researcher also needs to factor in ambient noise at various sites. Recordings in ship noise were made with the hydrophone placed at eight meters depth and situated such that the whale sub-pod was at a standoff distance of 100 meters (required by law) and the vessel was on the far side of the pod. A census of whales was taken at the beginning of recording and again upon completion. The pod remained grouped within a roughly 50 meter circle. Distance to the vessel from the ship was taken by radar and never exceeded 500 meters.

RESULTS AND DISCUSSION

Results were obtained on the following data:

A. Human vocalization signal versus noise level observation relationship.
B. Beluga vocalization signal versus noise level observation relationship.
C. Beluga vocalization signal versus noise level when there is a vessel present and when there isn't a vessel present.

A. Human vocalization signal versus noise level observation relationship

Five human female subjects read sentences two times for one trial and for a total of three trials. The first time there was no ambient noise, and the second time, the audiometer introduced noise to the subjects through earphones.

Table 2. Human Vocalization Levels in Response to Various Noise Levels.

SUBJECT	**Run No.**	**Q**	30 dBHL	40 dBHL	50 dBHL	60 dBHL	50 dBHL	40 dBHL	30 dBHL
S1	1	46.24	63.42	77.32	86.98	97.64	81.43	72.91	54.74
S1	2	42.02	63.50	74.25	84.33	97.36	81.64	72.00	58.26
S1	3	42.80	63.89	75.03	84.75	96.46	85.32	72.85	55.16
S2	1	48.22	65.26	75.83	85.11	95.10	80.31	74.33	62.50
S2	2	43.72	58.62	74.26	84.34	92.33	80.89	70.19	60.47
S2	3	41.44	57.58	74.60	84.31	90.24	78.69	70.51	60.69
S3	1	37.68	57.35	74.98	83.59	93.00	81.79	71.03	56.35
S3	2	40.73	57.00	74.89	81.57	90.68	81.68	71.59	55.11
S3	3	40.16	57.30	73.99	81.00	91.65	80.99	70.86	56.32
S4	1	38.44	52.94	68.31	77.75	91.80	75.47	69.14	54.87
S4	2	33.81	52.30	68.00	78.07	89.15	76.00	68.89	56.00
S4	3	32.75	51.70	69.88	77.85	89.56	75.98	69.75	54.67
S5	1	43.80	62.82	67.26	77.82	89.90	76.11	68.60	54.00
S5	2	40.03	63.68	67.74	76.06	89.07	76.00	70.48	55.51
S5	3	42.97	63.23	67.00	77.00	86.00	75.70	68.62	55.30

Q Quiet when the audiometer was introducing no noise.

Table 3. Average Human Vocalization Levels in Response to Various Noise Levels.

	Average Q	Average **56 dBSPL**	Average **66 dBSPL**	Average **75.5+ dBSPL**	Average **85.5 dBSPL**	Average **75.5+ dBSPL**	Average **66 dBSPL**	Average **56 dBSPL**
Trial		30 dBHL	40 dBHL	50 dBHL	60 dBHL	50 dBHL	40 dBHL	30 dBHL
1	42.87808	60.35844	72.73966	82.24978	93.48872	79.02257	71.20008	56.49195
2	40.06248	59.02166	71.82935	80.87242	91.71737	79.24093	70.632	57.06863
3	40.02354	58.74018	72.89046	80.98326	90.78119	79.33555	70.51786	56.42688
Average	**40.98803333**	**59.37342667**	**72.48649**	**81.36848667**	**91.99576**	**79.19968333**	**70.78331333**	**56.66248667**

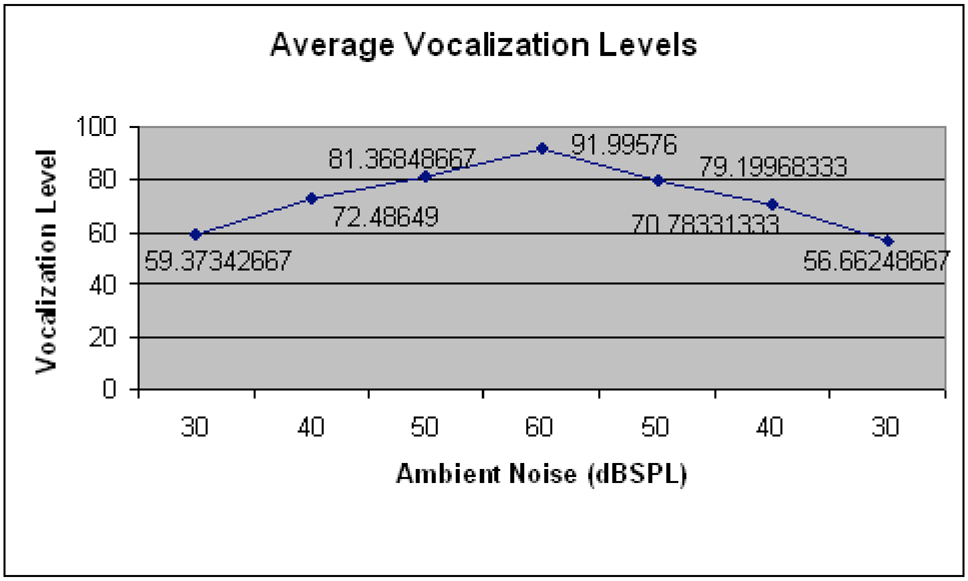


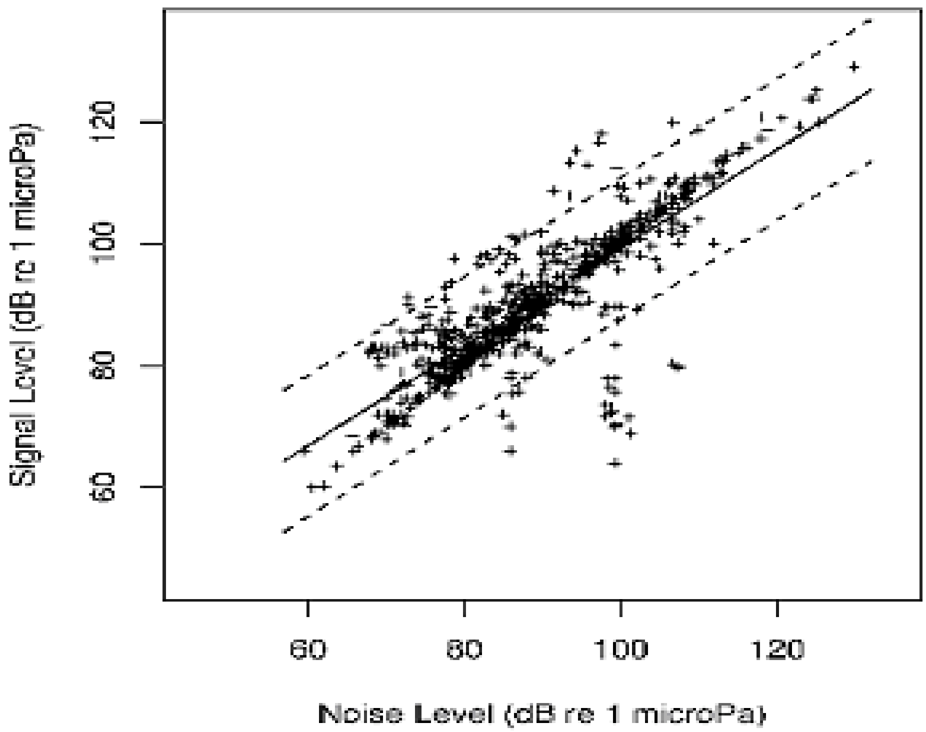
Figure 4. Average Vocalization Levels vs. Ambient Noise

Results from this data show that as ambient noise levels increased, the vocalization levels of the five subjects increased. As the ambient noise levels decreased, the vocalization levels of the five subjects decreased. The linear relationship indicates the existence of the Lombard Effect in humans.

B. Signal Versus Noise Analysis: The Vocalization as a Function of Noise Phenomenon

A direct correlation between vocalization and noise analysis was found through analysis. The sample size was N = 978. The coefficient of correlation was 0.795. The coefficient of determination was $r^2 = 0.7088$. This data proved that 70% of beluga vocalization changes results from ambient noise, proving that the intensity of beluga vocalization is directly correlated to the environmental noise. As the noise levels increased, the signal noise increased (Fig 2).

Figure 2. Regression of Beluga Vocalization Level (VL) Versus Changing Noise Levels from Extracted Beluga Vocalizations at All Sites in the Presence of Noise

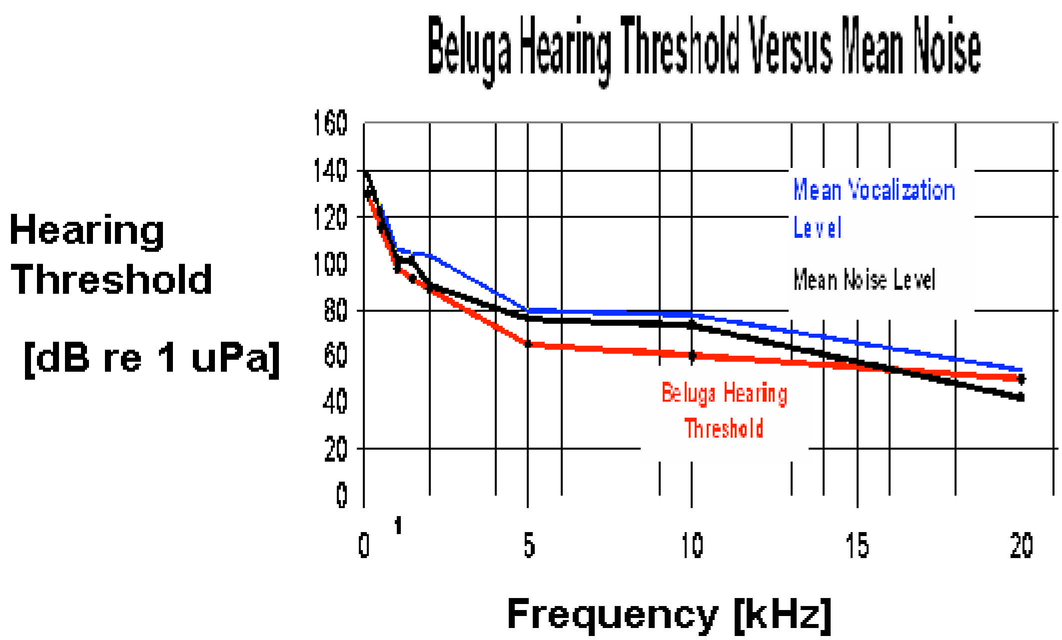


A regression analysis was conducted to further determine a correlation, and the results showed that there is a linear relationship between vocalization intensity and environmental noise levels.

C. Beluga Vocalization Signal Versus Noise Level With the Presence of Ambient Noise and Without the Presence of Ambient Noise

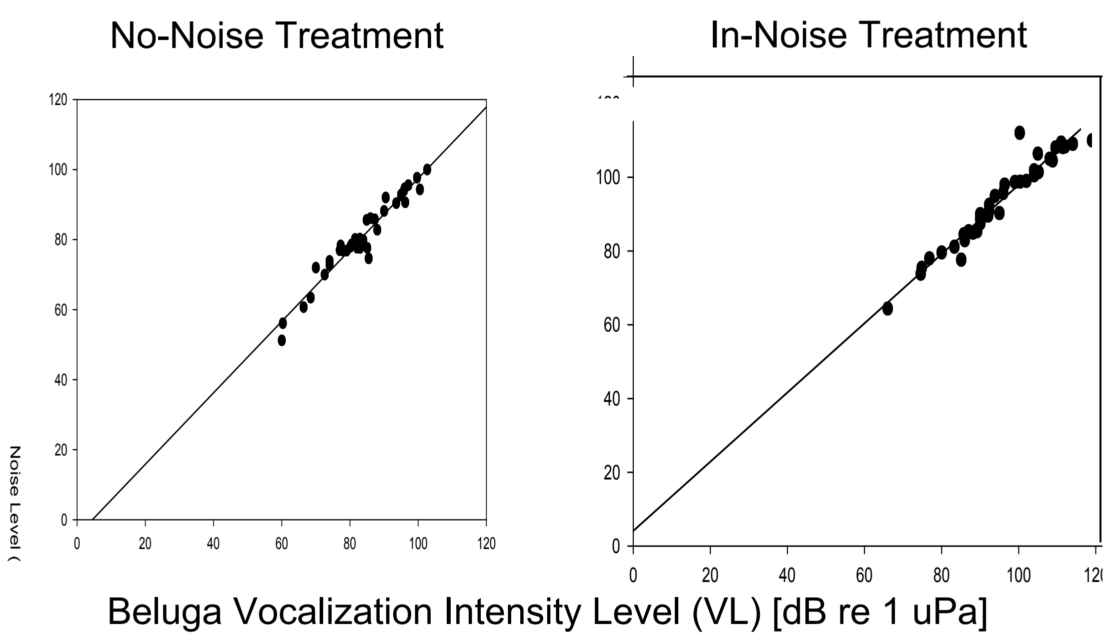
Two tests were conducted with the presence of ambient noise and without the presence of ambient noise, and a regression of the differences between ambient noise levels and no ambient noise levels were run. The ambient noise comes from the presence of a ship. The average vocalization level for belugas was above the average noise level, and above the beluga hearing threshold (Fig 3).

Figure 3. Mean Ambient Noise and Vocalization Levels Occurring During Vessel Present and No-Present Treatments Plotted Against the Beluga Hearing Threshold in the Sampled Frequency Range of 100 Hz – 10,000 Hz.



A regression was also run for the beluga vocalization level with and without the ship's presence. The confidence limits for vocalization in the no-noise condition were 86.76 to 80.46 while those for vocalizations made in noise were 99.1 to 91.74. The confidence interval is an estimated range of values which is likely to include an unknown population parameter, the estimated range being calculated from a given set of sample data. Great individual variability on the vocalization-as-a-function-of-noise phenomenon was shown as a result of the wide range of vocalization level increases within these confidence limits. The noise level of the vessel was above the hearing threshold of the beluga whales. As a result, the beluga vocalization levels increased to overcome the ambient noise levels.

Figure 4. Comparison of the No Vessels Present (No-Noise Treatment) and With Vessel Present (With-Noise) Treatment Regressions



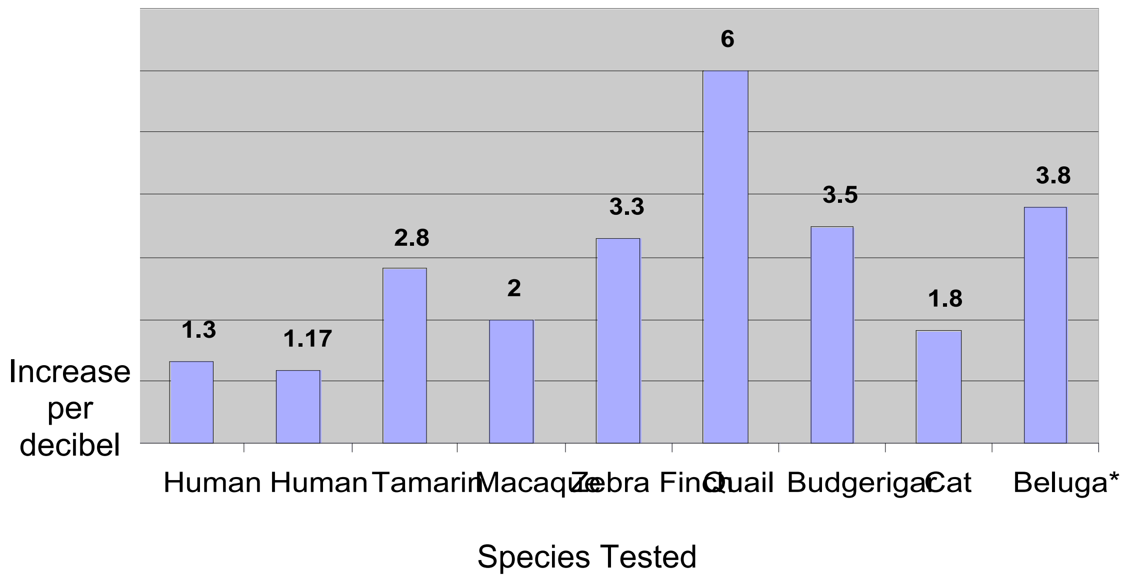
Beluga vocalization intensity level is higher during in-noise treatment (when a vessel is present), than when a vessel isn't present (Fig 4). Ambient noise level studies during 1996, 1998, 1999, 2001, 2002, and 2003 indicate that belugas in the St. Lawrence River Estuary are exposed high levels of ambient noise. The level of ambient noise is dependent upon weather conditions, bathymetry, tides, current regimes, topography, as well as anthropogenic additions, such as vessels. (Scheifele, 2001)

A cognitive explanation can be made as to the reason for vocalization level increases during conditions of high ambient noise. The specialization and development of specific areas of the brain are a function of environmental demands (Morgane and Jacobs, 1972; Morgane, 1974; Marino et al., 2003; Morgane et al., 1986a, b). Perhaps beluga vocalization levels increase because of the unique neural, auditory, and vocal anatomy and physiology of Cetaceans (Scheifele, 2001). In this experiment, 96% of the 978 belugas increased vocalization levels in response to ambient noise, and it is unlikely that a cognitive function could account for such a vast response in such a large group (Scheifele, 2001). A second explanation for the phenomenon is the existence of the Lombard Effect, and therefore the beluga vocalization levels increase as a result of ambient noise.

The correlation between ambient noise and beluga vocalization that was found in this study proves that the St. Lawrence belugas show a vocalization-as-a-function-of-noise phenomenon. The large sample size indicates that the vocalization level increases are influenced by physical factors, and the linear relationship between beluga vocalization and ambient noise levels typifies the Lombard Effect.

More evidence for the existence of the Lombard Effect in belugas comes from the linear relationship between beluga vocalization levels during the presence of ambient noise and without the presence of ambient noise. Figure 3 shows that vocalization levels are higher when there is ambient noise, a characteristic of the Lombard Effect. Former research on the Lombard Effect other animals as shown in Table 1 shows a vocalization increase similar to the data collected on beluga whales.

Table 1. Species Comparison of Vocalization Level Increase *versus* Noise Level Increase per Decibel



In every species tested, there is an increase in decibels in the vocalization level when there is ambient noise (Table 1). In beluga whales, there is an increase of 3.8 decibels in the vocalization when there is ambient noise present. In this experiment, the correlation coefficient for the belugas was 0.795 for the random site samples, and 0.9390 and 0.9355 for lack of ambient noise and presence of ambient noise recordings. The coefficients of determination were 0.7088 and 0.7552 respectively. The noise level compared to the vocalization level produced a linear regression line Y = .088x + 9.57 for the random site samples. The linear regression line for the lack of ambient noise and presence of ambient noise was Y=1.02x-4.571. The data from this experiment strongly implicates a Lombard Vocal Response in belugas. (Scheifele, 2001)

CONCLUSIONS

The collected data indicates an increase in vocalization levels as a result of an increase in ambient noise levels. The linear correlation between the vocalization and noise levels indicates that the Lombard Vocal Response is present in beluga whales (Delphinapterus leucas) and in humans (Homo sapiens).

The discovery and verification of the Lombard Effect in these two types of mammals opens many possible fields of research. The fact that this phenomenon exists in two different species may indicate a possible similarity between the auditory systems of cetaceans and humans. If there is a significant relationship between the two species, then medical research can be conducted on beluga auditory systems, and therefore indirectly on human auditory systems. Before a connection between beluga and human auditory systems was found, it was difficult to research the human auditory system. However, now that there is a known connection, research on belugas will serve as an indirect method to unlock the doors concerning the human auditory system.

ACKNOWLEDGEMENTS

A number of people have provided helpful comments on this paper. In particular, I would like to thank Dr. Peter Scheifele, Mr. Joseph Sencen, Mr. Michael Inglis, and my parents.

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