Jumping for Joy: Understanding the acoustics and communicative potential of percussive behavior in Southern Resident killer whales of the Salish Sea.

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Introduction

Percussive behaviors of cetaceans include pectoral fin slaps, fluke slaps (lob tailing) (both fluke slaps and pectoral fin slaps may be inverted), dorsal fin slaps, and breaching. While these behaviors have a visual component, they may be more stimulating to marine mammals in terms of the sounds they produce. In southern resident killer whales (SRKWs), percussive behaviors have been recorded and observed more frequently during summer, and in the presence of whale watching boats versus land-based observations (Williams 2002). This suggests that the behaviors are not random and therefore must serve some purpose. This study attempts to determine whether that purpose has the potential to be communicative.

In a study of Norwegian killer whales (Simon 2005), underwater tail slaps, used as a hunting method to stun herring, were recorded with source levels of around 186 dB (figure 2), with a frequency of 150 kHz for peak to peak measurements. Under water, these powerful tail slaps are thought to produce cavitation, which occurs when the vapor bubbles within a liquid implode under pressure. The sound produced by this underwater "thud" is beyond the hearing capabilities of orcas when compared with the audiogram for two captive orcas (figure 1). Of course, the purpose of these behaviors is for hunting rather than communication, so it is unnecessary for orcas to be able to detect such a loud sound after the prey has already been detected. However, replicated surface percussive behaviors in this experiment have resulted in amplitudes well within the auditory capabilities of an orca (figure 3).

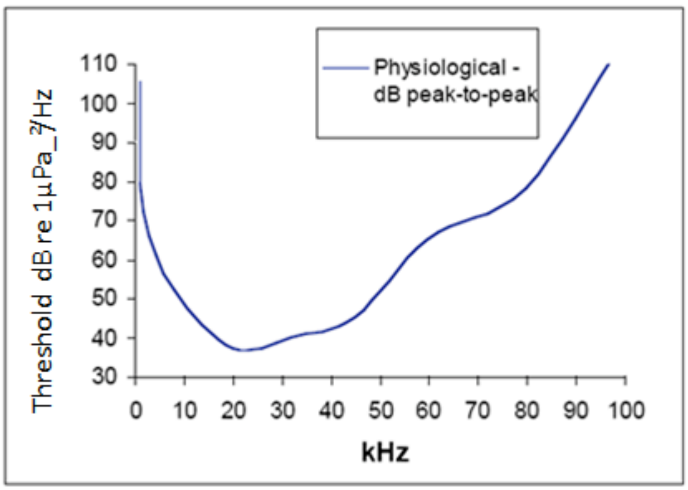

Figure 1. Killer whale audiogram showing physiological threshold (simplified from Szymanski *et al.* 1999)

(Reproduced with minor modifications from Hunt 2007)

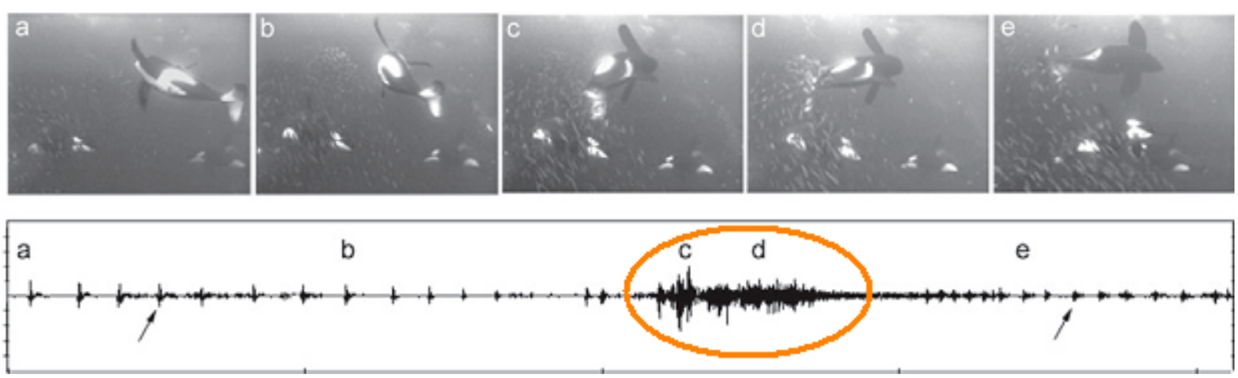

Figure 2. (Simon, M. et al. 2005) shows the acoustic progression of an underwater tail slap. a, b and e are echolocation clicks, c and d show the acoustic impact of the tail slap.

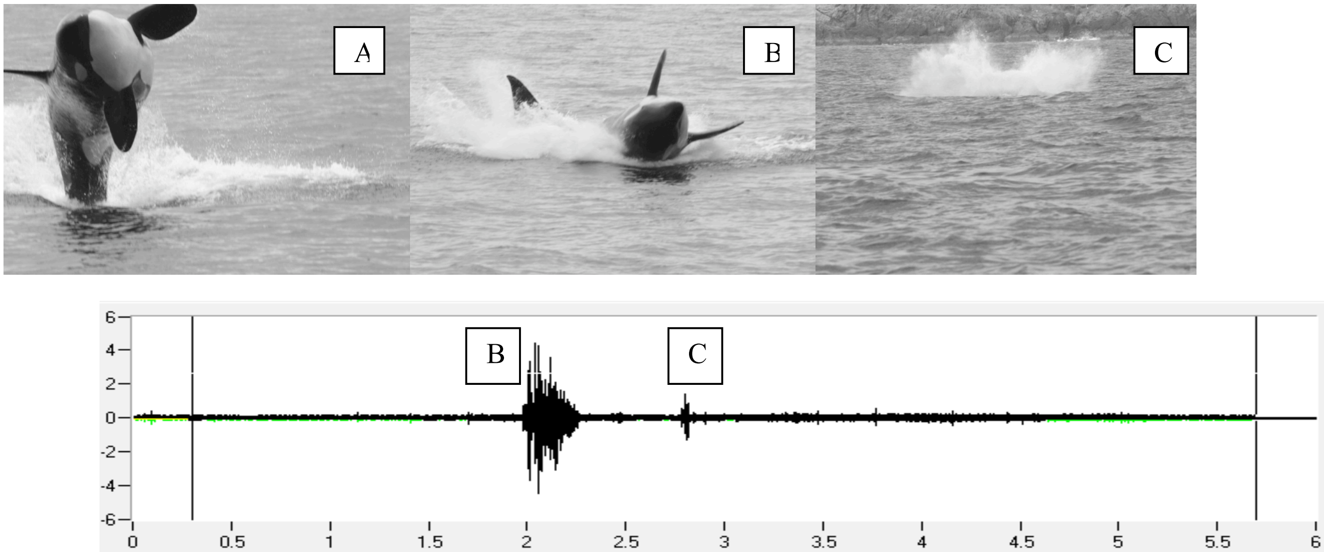

Figure 3- The acoustic progression of a breach. B is the initial impact and C is the water slapping back together.

SRKWs use a complex variety of calls, whistles and signals to communicate with one another. Many of these sounds have been recorded, analyzed and catalogued, yet the percussive sounds made by common SRKW behaviors such as breaching and tail slapping has not been thoroughly investigated. Percussive behaviors are much more common in Resident orcas than in transient orcas, likely because such sounds may have negative effects on foraging success since marine mammal prey would easily be able to detect this behavior (Baird 2000). Southern Resident orca whales prey mainly on salmon, specifically Chinook. Because Chinook are found deeper than other species of salmon, detection of these percussives by the orcas' prey is not a concern. This study will be useful because the acoustic properties of percussive behaviors in Southern Residents killer whales have not been examined or assessed in their feasibility as a potential means of communication. Southern Resident killer whales undergo anthropogenic environmental stress through call masking (Erbe 2002). Percussive behaviors are more likely to be masked in the presence of high boat traffic. If potentially communicative signals are being masked, there may be implications for policy and further restrictions regarding vessel proximity to orcas. Further suggestions have been made that percussive behaviors are an aggressive or irritated response and have the potential to be used for interspecies communication as well as communication among con specifics. Do SRKW percussive behaviors have the potential to be used as a form of communication?

Methods:

The hydrophone array was deployed from the stern of the Gato Verde, a sailing research vessel catamaran, during each session with whales. A twelve pound weight was suspended to keep the array submerged in the water while the vessel was moving. The sound files and times were recorded on Sound Device 702s. When percussive events were observed, the recording time, file, and type of event was recorded. The times of the percussive events were then viewed using OVAL software to determine which, if any of the events were visible on the spectrogram and/ or audible. If the percussive event was audible, the OVAL software was used to determine the Fast Fourier Transform values, frequency, and amplitude of the percussive. The square root of the RMS of the sound plus noise squared minus the RMS of the background noise squared was calculated to get the RMS of the sound alone (Equation 1) and then 20 times the log of the RMS of the sound alone was taken and added to the known sensitivity (Equation 2), which was 143 for all of the array hydrophones to find the Received level amplitude.

Equation 1: $RMS_{sound}=\sqrt{(RMS_{sound+noise})^2-(RMS_{noise})^2}$

Equation 2: Received level (dB re 1μPa) = $20 * \log_{10}(RMS_{sound})+143$

To find the source level at 1 meter, the distance of the percussive event had to be found by using the Ishmael 1.0 (David Mellinger) software for localization. When the distance was found, the Pythagorean Theorem (Equation 3) was used to determine the range after the coordinates were given. Some of the initial impact of the sound is lost by the time it reaches the hydrophone array--in this case, spherical spreading is assumed. The equation 20 times the log of the range/1 meter was used to attain the spreading loss (Equation 4). The received level was added to the spreading loss to attain the source levels at 1 meter (Equation 5).

Equation 3: $a^2 + b^2 = c^2$

Equation 4: Spherical Spreading Loss = 20 ($\log_{10}$ (range/1m)).

Equation 5: Source Level (dB re 1µPa @ 1m) = Received level + Spreading Loss

Because the actual slaps were not impulsive as hypothesized, the first and second part of the breach was analyzed separately to give two data samples for a single breach. The initial sound represented the whale hitting the water, and the second sound was the water slapping back together (Figure 3). To make the simulated percussive sounds, a four and a half by 3 and a half sheet of plywood was cut into an orca fluke shape with a ban saw. The edges were sanded to make handling easier. The single 18 horse power outboard inflatable was deployed from the Catamaran and positioned 100m from the Gato Verde. The Catamaran moved forward past the stationary dingy until it was 100 m away from the opposite side of the inflatable. As many simulated slaps as possible were performed during this period from the inflatable. A colleague used a range finder to attain the distances at time intervals for each slap. The slaps were recorded using the hydrophone array and the gains were set to 37 for each channel.

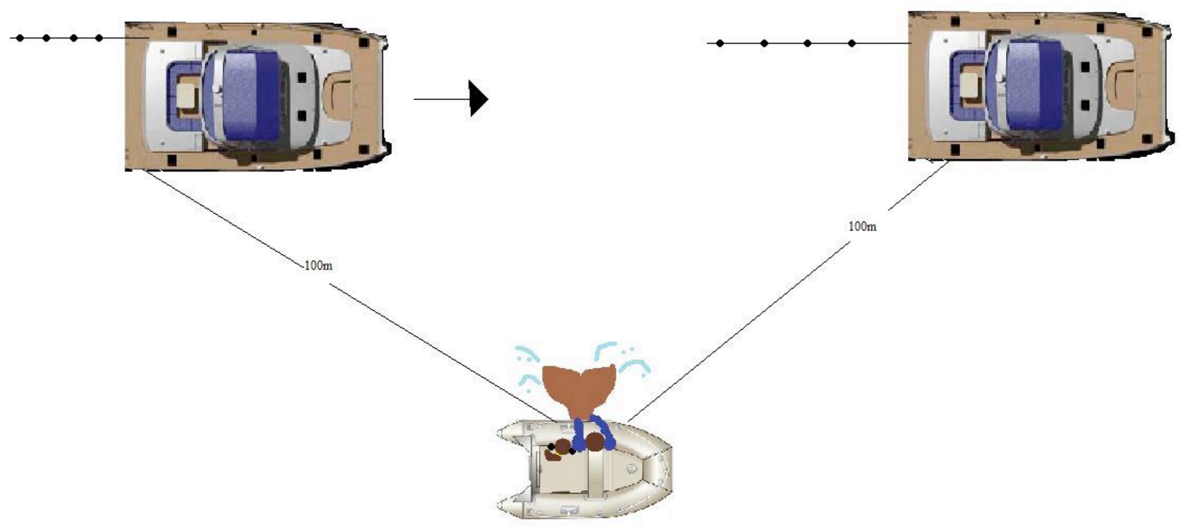

Diagram 1: Procedure for recording simulated tail slap data. The hydrophone array is towed behind the Gato Verde Catamaran Research Vessel for the duration of the recording time.

Three of the samples (A23_1prevost, A24_1prevost, and A25_1prevost), were recorded at the dock in Prevost Harbor in the San Juan Islands. The other four samples (A09fhl, A10fhl, A11fhl, and A14fhl), were recorded at the Friday Harbor Laboratories' dock in Friday Harbor, San Juan Island. The first three samples were recorded using the high frequency CRT (Cetacean Research Technology) hydrophone with distances of 30 meters, 20 meters, and 8.5 meters respectively. A flat wooden slab was slapped against the water by a colleague for each of the recordings. This slab was intended to simulate a pectoral slap, and the conditions at Prevost Harbor made this type of data collection ideal as neither natural nor anthropogenic noise interfered. The gains for the first three samples were set to 37, 20 and 20 respectively. (Diagram 2).

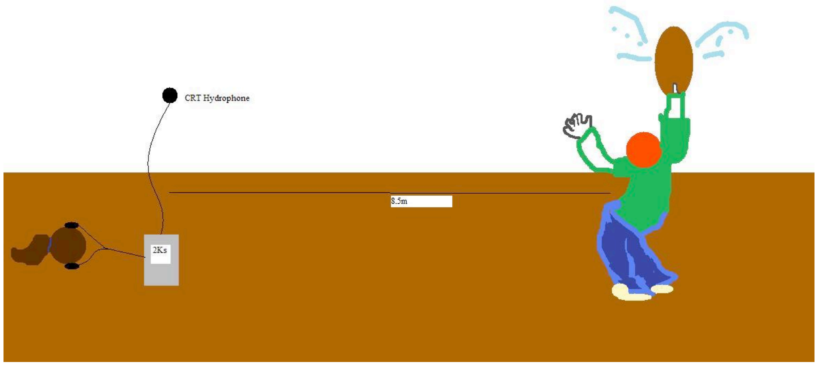

Diagram 2- Procedure for performing simulated pectoral fin slaps. The CRT was suspended from the dock and the Sound Device 702 was used for recording.

The FFT values from the OVAL software were stored for all the real and simulated percussives to be statistically tested. An average simulated tail slap sound and waveform were compiled by breaking the .wav files into single .125 second recordings in the software, MatLab. An average frequency for all percussives was found by using the stored powers and averaging the powers of each sample, then dividing by the total number of slaps. The log of the average powers was taken and then multiplied by ten to attain an average received level for percussive events in an excel spreadsheet. Minitab analyzing program was used to perform significance tests (one-sample t-tests) on all of the data.

Results

A one way t-test was performed on the source levels of the actual percussive events against the source levels of the simulated percussive events and the p-value was found to be .50. The one-way t-test indicated that the pseudo-tail slaps were acceptable to use as a replication method for actual percussive events. Because the p-value is greater than .05, the null hypothesis that simulated percussive events are similar in source level to actual percussive events cannot be rejected. This increased the sample size for percussive events significantly because the simulated percussives were proven to be an accurate representation of actual percussives. The mean source levels in units dB re 1 μPa at 1 m for both known communicative signals and percussives are represented in table 1. The p-values for actual and simulated percussive events in comparison to known communicative signals are represented in table 2. The percussive events are shown to be statistically insignificant in each of these cases p<.001. The only case where a percussive event which had a lower average amplitude than a sample was in comparison with an echolocation click. Percussive events do have the potential to be used for communication as their average source levels are louder than all other tested communication signals.

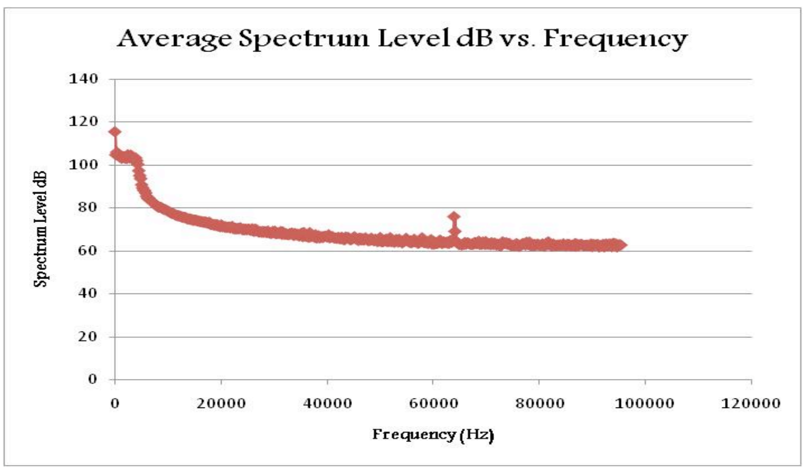

Figure 4- Average amplitude at increasing frequency for all percussive events

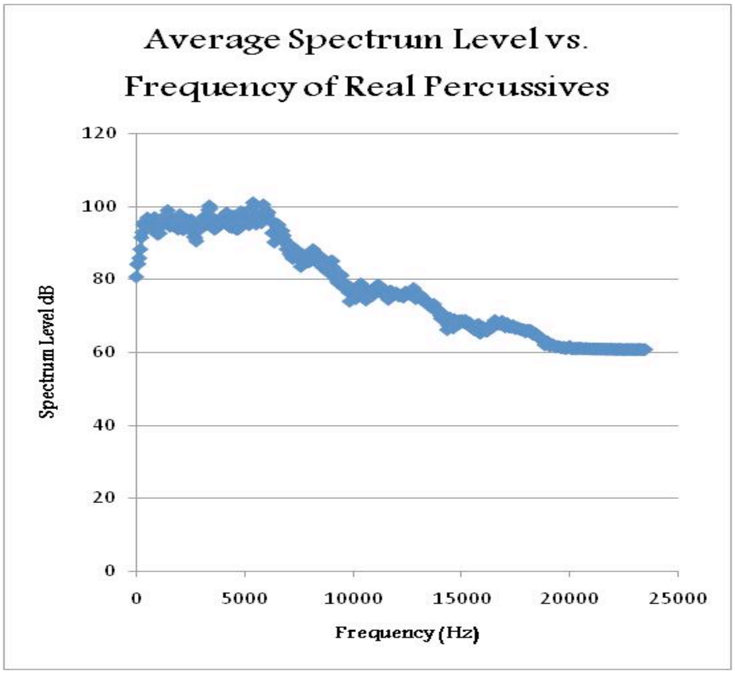

Figure 5-Average amplitude at increasing frequencies for real percussive events only.

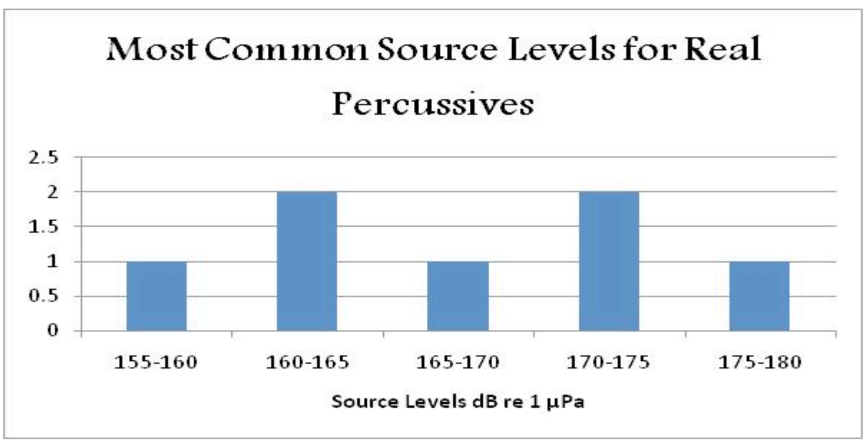

Figure 6- Most frequently occurring source level ranges for real percussive events. N=7

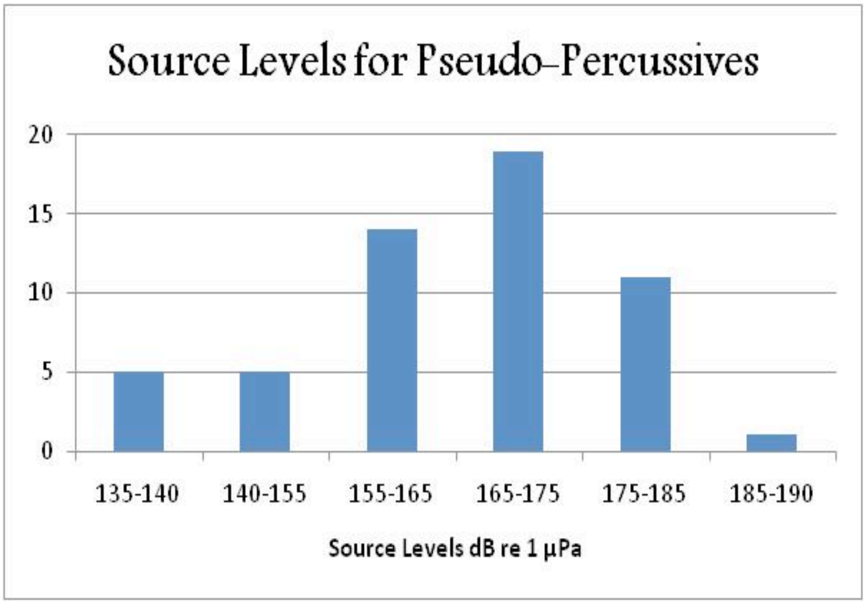

Figure 7- Most frequently occurring source level ranges for simulated percussive events. N=55

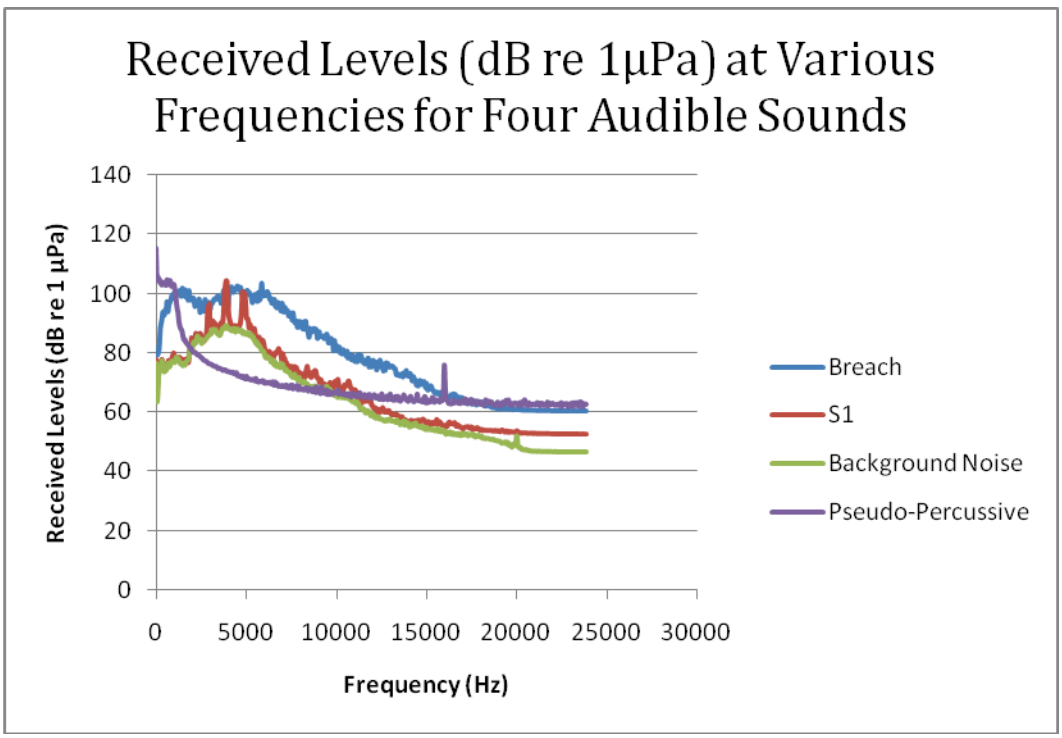

Figure 8- Comparison of a real breach, an S1 call, a pseudo-percussive event, and background noise. Note: breach, S1, and background noise are all sampled from the same file and time period.

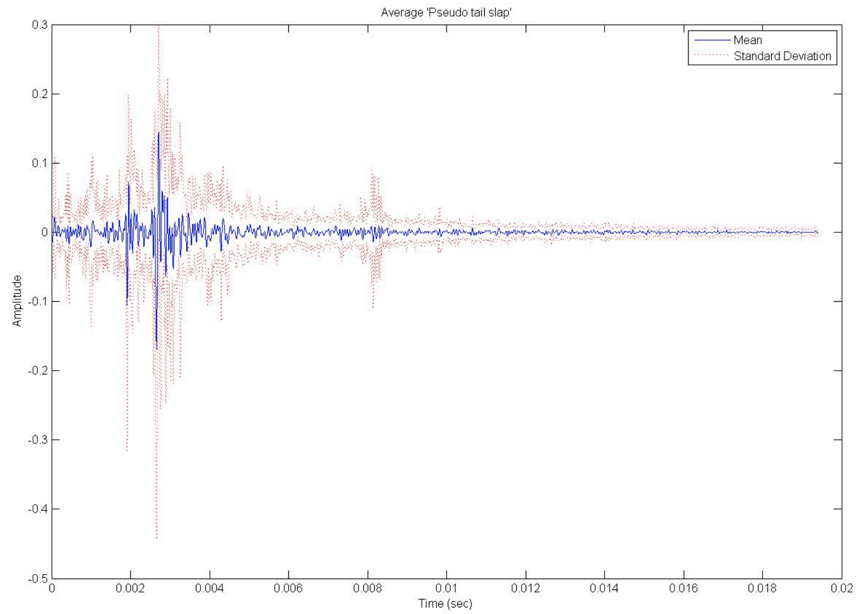

Figure 9- Average Waveform for a simulated percussive event

Whistle	140.2
Variable Call	146.6
Stereotyped Call	152.6
Echolocation Click	193
Simulated Percussive	164.44
Real Percussive	167.87

Table 1- average source levels for percussives and communicative signals used in one-sample t-tests. (Call and Whistle Source Levels by Miller 2006, Echolocation Click Source Level by Au, Ford, Horne)

	Real Percussive	Simulated Percussive
Whistle	p<.001	p<.001
Variable Call	p<.001	p<.001
Stereotyped Call	p<.001	p<.001
Echolocation Click	p<.001	p<.001

Table 2- p-values for real and simulated percussive events in comparison with other known communicative signals

Discussion:

The results show that percussive events have the potential to be used for communication and are comparable to other communicative sounds in amplitude. Because of the difficulty in obtaining an audible percussive sound, every audible event was used and a random sampling rate was unnecessary. The difference in frequency between percussive events and known communication signals may be considered a more significant barrier to the use of percussive events as an effective means of communication. The p-values show that the amplitude of the percussives (both real and simulated) are significantly different (higher except for clicks) than all of the other communicative signals such as S1 calls, whistles and clicks. The percussive events are well within the audiogram of an orca whale, but may often be masked in severe weather conditions such as high wind and waves, or in high levels of boat traffic that contribute to ambient noise. The simulated percussives were shown to be not significantly different than the actual percussives, with a p-value of 0.5, which allowed them to be used as acceptable models for actual percussive event data and effectively increase the sample size in this experiment.

The communicative significance of percussive events needs further research. The experiment on percussive events could be improved if a count of vessels present during percussives is taken. This would obtain an accurate understanding of the masking of these events and how it could compromise their audibility when surrounded by high vessel traffic. A similar improvement would be to sample percussive events in various weather and sea conditions to determine if the effect of natural ambient noise is masks percussive events. The policy and regulation implications to prevent the effects of masking another potential form of communication will be critical in protecting and preserving southern resident killer whales.

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