**Direction change instigation ‘signals’ in *Orcinus orca.***

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*Orcinus orca* is the largest whale in the *Delphinidae* family. Orcas are classified into three distinct ecotypes in the northeastern Pacific Ocean: Transients, Offshore and Residents. Each ecotype is distinct in its behavior, morphology, ecology, and vocalization repertoire. Significant genetic differences among the ecotypes indicate that they do not interbreed (NMFS 2008, Ford 1991).

Among Residents on the west cost of the US and Canada there are 4 different communities: Southern Residents, Northern Residents, Southern Alaska Residents and Western Alaska Residents (NMFS 2008, Ford 1991, 1987). The Southern Residents will be the focus of this study.

Orcas have a complex social structure which is theorized to be the reason for the complexity of their vocalizations which seem to send information among orcas in a form of communication. There are three categories of vocalizations: clicks, whistles, and pulsed calls (Ford 1991,1987).

Pulsed calls are defined as strings of pulses so close together that they sound like a single tone. They last from 50 milliseconds - 10 seconds long and have an average frequency ranging from 1-6kHz (Ford 1987, NMFS 2008). These calls are broken into three categories: discrete, variable, and aberrant (Ford 1987, 1989). It is thought that their function is to help maintain group identity and contact.

Clicks are very short bursts of sound that have been observed to occur frequently when orca are active (Ford 1989), though they also occur during resting behavior. Click rates vary and can occur from very few to over 300 clicks per second. Rapid-fire clicks usually have no audible separation between individual clicks and are called buzz trains. Clicks are thought to be used mostly for navigation and foraging, but since they also occur during social interaction, and information from clicks is shared, it is thought that they may serve a communicative function as well (Barrett-Lennard et al. 1996, NMFS 2008). Buzz trains also occur during certain discrete pulsed calls such as S37 which is a buzz followed by a discrete pulsed call this is the characterizing part of the S37 call.

Whistles are continual tonal calls with harmonics that last about .06 - 18.3 seconds. They have a high average dominant frequency of 8.3kHz. In most whistles, there are harmonics around a fundamental frequency (Thompson et al. 2001). Whistles, like discrete calls, have discrete and variable call types (Reisch et al. 2006). Among the Southern Residents, whistles are most commonly used both during foraging and socializing (NMFS 2008, Ford 1987, 1989), and in situations when the individuals of the pod are more than 10m away from each other (Barry 2006).

Orcas’ complex social structure is mirrored in the existence of dialects that differ among clans, pods and matrilines. Dialects are characterized by differences in vocal repertoires and acoustics (Ford 1991).

Because light doesn’t travel very far in water but sound does, it is theorized that marine animals must rely on sound to keep in contact with each other (Myberg 1980 in Miller et al. 2004). Vocalizations are very important when studying marine mammal behavior because they are a large part of how animals interact with one another and observing their physical behavior can be extremely difficult. As one of the only ways scientists are able to research free-ranging orcas, decoding the information in sounds is very important to understanding both their communication and behavior. Understanding how they communicate and what drives their behavior will help scientists better understand the impacts of human presence in their habitat and thus their ability to not only thrive but to survive.

Both Bigg et al. (1987) and Ford (1987, 1991) thought that discrete pulsed calls were significant because of their frequent occurrences and their importance in creating the differences among dialects. Recently Reich et al. (2006) documented discrete whistle types. Both Thomson et al. (2001) and Reisch et al. (2006) found that orca whistles are much more complex than previously suspected, and, among Northern Residents, most commonly occur during socializing behavior leading scientests to believe that, like discrete pulsed-calls, they are important to communication. Barry (2006) theorized that because Southern Residents have the highest whistle rate during rest and when the whales are at distances of greater than 10m, whistles may have a communicative function primarily between members of the same pod as whistles don’t travel as far as pulsed calls and clicks.

Miller (2004) found that orcas exhibit call-type matching behavior, in which after one whale calls, another will often respond with the same or very similar call. He also found that of the one or two most frequent calls produced, those calls occur in series a significant percent of the time. Weiland (2007) found something similar: that the most frequent call had patterns of repetition and that the calls are not random sounds, but have some structure leading to the idea that is communication.

Like Weiland (2007) and Miller (2004), Morton (1986) studied sequence patterns in vocalizations of captive Northern Residents as well as the correlation of sounds and behavior. She concluded that when the frequency of calls was measured during different behavior states, there were correlations between behaviors and calls. She also suggests that there is a high degree of order in ‘sound sequencing’ and found that a sound that she called ‘F1’ was frequently repeated at both the start and stop of ‘conversations’.

Although the aforementioned scientists have found many interesting call pattern occurrences, no study on the existence of direction change instigation calls in free-ranging orcas has been pursued. This topic warrants further study because knowledge of behavior triggering patterns in vocalizations may allow biologists to better understand behavioral trends and patterns as well as group cohesion and decision-making. In addition, his knowledge would allow biologists and conservationists to understand how behaviors may be changed by outside influence. It would further their ability to study short and long term behavioral shifts due to factors such as food quantity, disruptions in their movements and activities as well as to understand if masking calls could result in pod dispersal and the unintentional separation of individuals from the pod.

It is common in some terrestrial animals and birds for an individual to signal for group movement or change of foraging area (Radford 2004, Boinski 1993, 1996, Bradbury 1998). Woodhoopoes, white-faced capuchin monkeys and squirrel monkeys have been found to have certain calls that instigate troop movement and direction change. (Radford 2005, Boinski 1993, 1996, Boinski & Campbell 1995). Boinski & Campbell (1993, 1995) found that white-faced capuchins’ trills occurring during movement served to maintain contact, directionality and trajectory. They found that trills were the only call that triggered group movement and orientation demonstrated by white-faced capuchins who were visually separated from their group and who would periodically orient themselves to the others but only in response to a trill (Boinski 1993, Boinski & Campbell 1995).

The Pacific Ocean is, in some ways, not that different from the forests in which woodhoopoes, squirrel monkeys and white-faced capuchins live. In these kinds of habitats visibility is low when individuals spread out during travel and foraging, making vocalization vital to group cohesion, movement, direction and identity (Radford 2004, Boinski 1993, 1996).

In light of these similarities in habitat which could lead to similarities in group movement initiation, I have decided to focus my study on the following questions: Does a higher call rate occur shortly before direction change? Does a higher buzz rate occur shortly before direction change?

To investigate these questions I will test the following hypotheses: 1. Prior to pod direction change, calls occur at a higher rate than occurs than occurs after pod direction change. 2. Prior to pod direction change, buzzes occur at a higher rate than occurs than occurs after pod direction change.

Methods

In order to gather data which would allow me to investigate whether pod direction change is instigated by a vocal signal—a vocal signal being a call or buzz rate change—I undertook two types of data gathering: acoustic recording and behavioral observation.

Due to the infrequent and brief encounters with the Southern Residents, historical data was used for most of the study data. This data was obtained from Dr. Otis at the Lime Kiln lighthouse. The pertinent data from his data sheet are as follows: the date, the number of whales seen, the start time of observation, the turn time and the end time of the observation period.

Additionally I collected my own data from a 42’ electric motor powered catamaran named *Gato Verde* which was used as a mobile research platform for orca observation. Data was taken in the northern inland waters near or among the San Juan Islands, as the Southern Resident Killer Whales consisting of J, K and L pods, who are the focus of this study, tend to spend most of their time there during the late spring and summer. During observation times, the *Gato Verde* was kept at least 100m from the orcas when traveling parallel to them and 400m from the path of the whales at all times as suggested by the Whale Watch Guidelines.

**Acoustic Study**

The acoustic data from Lime Kiln was collected from 2001 to 2008 from many different hydrophones. Using the date and time from a spreadsheet the correlating recordings, stored on a computer hard drive, were analyzed using Audacity.

To obtain the acoustic data a Lab Core 4 hydrophone array, with a peak sensitivity at 5kHz connectedto two Sound Device 702 solid-state audio recorders was used.

The hydrophones were approximately 10 meters apart beginning with hydrophone number one, the one closest to the stern port engine; the hydrophones were deployed horizontally behind the *Gato Verde*. The hydrophones were positioned approximately 3.75 meters (depending on our speed) under the surface of the water by a weight of 8 lb. and were spaced beginning approximately 6.5 meters (depending on our speed) from the stern port engine of the *Gato Verde*. The hydrophones were each approximately 10 meters apart (1-2 is 9.93m, 2-3 is 9.78m, 3-4 is 9.96 m). This kept the hydrophones from getting caught by other ships that might have too close to the stern of the boat.

The Sound Device’s gains were set at 37 dB and the sampling rate was 44.1 kHz. When the orcas were present and vocalizing, the hydrophones were turned on and recording begun in real time with a start time recorded for the beginning of every new file, so the acoustic and behavioral data could be compared accurately.

**Behavioral Study**

The behavior portion of this research focused on pod direction change. I defined a direction change as any change in direction that was of an angle between 90° and 180° from a previous direction. The new direction heading had to be kept for at least 12 minutes, so milling behavior and non-directional movement were not counted as rapid changes in direction. A change in direction was not recorded unless it occurred when approximately 70% of the pod changed direction.

The behavioral data from Lime Kiln was taken as the orca entered a pre-designated area and stopped when they left. For every observation period the number of whales were counted and the occurrence of a turnaround (North to South and vise versa) was noted; the time of turnaround was also noted on many of the spread sheets, more reliably so in the later data as the spreadsheet and data taking methods evolved.

The behavioral data taken onboard the Gato Verde was recorded on one data sheet containing the following three columns: time, direction and number of whales. Each data sheet included the acoustic file number as well as the time the recording was started allowing the audio and behavior data to be matched for analysis. I used continuous all occurrence sampling to collect the behavior data on the data collection sheet.

For each research encounter with the orcas the number of individual whales present was recorded in order to have the information necessary to calculate a call rate/individual/minute. The number of individuals was counted at the beginning of the encounter and if a change in numbers occurred the new number was recorded with the time at which the change occurred. These numbers were compared with the number of individuals that other researchers on *Gato Verde* counted.

**Analysis**

The total number of calls occurring during the six minutes before and after a direction change were acquired by importing a .wav file to Audacity and simultaneously watching the continuous spectrogram and listening to the recording. Every time a call was heard it was marked down so a final tally could be taken of all the calls during the six minute analyzed period. To get call rates the total number of calls for the six minutes before and six minutes after the direction change were divided by the number of whales present and the six minutes over which the calls were recorded. This data was square root transformed, to normalize the variance, before running a paired t-test.

Buzz rate acquisition during the six minutes before and after direction changes followed the same protocol as call rates. The data was then Log10 transformed, to normalize variance, before a paired t-test was run.

Calls were defined as any discrete, aberrant or variable call or whistle. Buzzes were defined as a series of independent (not attached to a call) clicks so close together that individual clicks could not be discerned from one another. S37 is an example of a buzz attached to a call; in that case the buzz was counted as a call not a buzz.

In many recordings the background noise at points, mainly caused by passing ship and boats but occasionally flow noise as well, was loud enough that it potentially masked the calls, making it difficult to determine accurate call and buzz rates. In the Lighthouse data, because the hydrophones were stationary and the whales weren’t, occasionally the whales would get far enough away that faint calls were hard to hear over background noise. The matter of human error was also doubly as pertinent because the historic data was recorded and entered into the computer by one person and then extracted and analyzed by another. The number of researchers recording and transcribing heightens the possibility of data entry mistakes. Orcas generally turn around under water meaning that an exact time of direction change cannot be known; therefore, the observer must estimate the time of direction change and may record the change later than it actually occurs. Sound files are also sometimes mislabeled meaning that the sound file start time and the labeled start time may be different, thereby affecting data analysis accuracy.

The behavioral and acoustic data was examined together to determine whether or not there was a significant difference between call and buzz rates six minutes before and after the direction change. The data collected constrained the amount of time before direction changes that could be analyzed and six minutes before and after was the best compromise between number of analyzable instances and a longer amount of time in which direction change instigation calls could occur.

To investigate whether or not there was a difference in the call and buzz rates before vs. after direction change a paired t-test was used. This test was chosen as it took the relationship between the call rates before and after individual direction change events into account.

Results

26 direction change events were analyzed. The number of calls and buzzes six minutes before and after every direction change event were entered into a Microsoft Excel sheet for organization and analysis. Call rates were calculated for each event by dividing the number of calls by number of whales present and the six-minute time duration. The program StatPlus was used in conjunction with Excel to run the statistical tests.

Call rates six minutes before direction changes, with an average of1.05, were higher than call rates six minutes after, with an average of 0.82, but not significantly so (p-value = 0.60) see Figure 1.

Figure 1. The mean call rates occurring six minutes before and six minutes after a direction change.

Buzz rates six minutes before direction change mean with a mean of 0.18 were significantly larger than buzz rates six minutes after with a mean of 0.05 (p-value = 0.006) (Figure 2).

Figure 2. The mean call rates (and SEM) occurring six minutes before and six minutes after a direction change.

Discussion

Scientists have been trying to link pulsed calls and whistles with behavioral states and meaning for a very long time and have yet to succeed. Calls may be much more complex and have inherent patterns that we have yet to understand that may make all the difference. Sometimes they turned around in the middle of call bouts.

Buzzes have been seen as just an extension of clicks and click trains since scientists have determined how each kind of vocalization was produced. I believe that buzzes may serve a different function. Buzzes are the only clicks that are inherently associated with discrete calls and communication. They very probably do serve as echolocation clicks but that doesn’t also mean that they have a communicative function as well. Recently Barrett-Leonard et al. (1996) found that echolocation clicks may not be used as heavily for echolocation and finding food but rather use passive acoustic monitoring to forage and are not as deft as thought at avoiding objects using echolocation.

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