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An Alternative Sperm Whale (*Physeter macrocephalus*) Coda Naming Protocol

Mike van der Schaar and Michel André

Laboratori d'Aplicacions Bioacústiques, Universitat Politècnica de Catalunya (UPC), Spain

Abstract

Codas are characteristic acoustic signals that sperm whales produce in social contexts. They consist of a short series of pulses that are repeated several times within a short time interval. The analysis of these codas and their possible group specificity have led some authors to believe that they may also help understand population trends and geographical separation. The use of a consistent tool for their comparison, therefore, appears necessary to confirm these assumptions on a wide scale. Coda classification is currently achieved by clustering codas into different types based on the number of clicks per coda and their normalised inter-pulse intervals. This labelling does not follow a clear protocol, however, making it difficult to compare results from different studies. Therefore, an alternative naming protocol for labelling the normalised coda clusters is suggested. The goal of the protocol is to remove ambiguity and subjectivity from the current naming schemes and to give a systematic approach to labelling the clusters by a characterisation of their rhythm. The protocol is demonstrated on coda vocalisations recorded near the Canary Islands.

Key Words: sperm whale, *Physeter macrocephalus*, codas, classification, Canary Islands

Introduction

Sperm whales (*Physeter macrocephalus*) produce a limited combination of acoustic pulses consisting of usual, rapid, or slow clicks as well as creaks and codas. The usage and importance of these signals are poorly understood, but codas are believed to play an important role in the communication of socialising sperm whales (Watkins & Schevill, 1977; Whitehead & Weilgart, 1991; Pavan et al., 2000). They consist of a short series of clicks repeated several times and are mostly heard when the whales are gathering at the surface. It has been speculated that codas are group specific and vary depending on the geographical location (Moore et al., 1993; Weilgart & Whitehead, 1997; Whitehead et al., 1998). Considering their (assumed) social importance, codas form an interesting subject for study. A difficulty in comparing the results of different studies is the lack of a clear standard to name coda classes. Currently, codas are divided into different types based on the number of pulses and the inter-pulse intervals. Before the codas are analysed, they are normalised by dividing every inter-pulse interval by the total duration of the coda (which is commonly defined as the time between the start of the first pulse and the start of the last pulse). After normalisation, the codas are clustered into different groups, and each of these groups is then labelled by their average rhythm.

Current labelling schemes focus on counting the number of pulses within a coda, grouping pulses that are "closer" together. The definition of *closer* is left to the researcher and can be arbitrary. An example is given in Figure 1, which shows two normalised 5-pulse codas (the vertical bars are the coda's pulses). The coda on the left would be called "1 + 2 + 2," which could also be the label for the coda on the right, discarding information about the different time intervals. In the event that the codas were found in different studies, comparison of the coda types "1 + 2 + 2" would lead to erroneous conclusions. If both coda types were found in the same study, then the left coda may be renamed to, for example, "1 + 2 + + 2" to indicate the different rhythms; however, without any other information about the meaning of double or more plus signs, comparison between studies is impossible. Authors need a certain amount of creativity and imagination to label the clusters found, using a mixture of characters and plus signs. Therefore, an alternative protocol is suggested herein that preserves interval information and closely describes the coda rhythm.

Materials and Methods

Data Collection and Preparation

Our data was collected from 1993 to 1996 among the main islands of Gran Canaria, Tenerife, and Fuerteventura in the Canary Islands (André, 1997). A two-hydrophone array was used for the recording, consisting of two Benthos AQ-4 elements (frequency response: 1 Hz-15 kHz), with two Benthos AQ-501 pre-amplifiers (frequency response: 1 Hz-15 kHz; 32 dB ± 0.2 dB gain). The data were stored on a Sony TCD II Pro DAT recorder at a 48 kHz sampling rate.

The codas were manually located in every recording and kept if they had both a good signal-to-noise ratio and were clearly distinguishable from overlapping or successive codas. Additionally, they had to be repeated at least once to be considered for analysis. The start of the first pulse was taken as the start of the coda, defining the pulse intervals as the duration between the start of a pulse and the following pulse. The codas from all tapes were combined and then grouped by the number of pulses and normalised by their duration. These groups were then clustered using a method based on *k*-means as described in Hamerly & Elkan (2003).

Labelling Method

The proposed protocol aims to avoid any kind of subjectivity in the labelling of coda groups. As with the current naming schemes, there are two parts that are used in labelling: (1) the characterisation of inter-pulse intervals and (2) the grouping of consecutive pulses that have similar lengths.

Pulse Interval Labelling—Starting with labelling the intervals, it is required that the codas are normalised by duration, which is the case in practically every coda study. The normalisation implies that codas are analyzed by their rhythm and suggests the use of a labelling algorithm that follows this rhythm (i.e., the inter-pulse intervals) closely. A systematic approach requires a partitioning of the pulse interval lengths in a number of types. Current schemes make use of a regular interval type, in which the pulses are more or less evenly spaced, and a number of plusses (+) that signify longer intervals relative to the shorter intervals in the specific coda cluster. Putting this in a more structured and objective framework, a perfectly regular coda consisting of n pulses would have pulse intervals of $\frac{1}{n-1}$. Using this interval as a unit length, we can then proceed by dividing the inter-pulse interval in segments to characterise the different interval types. Since current coda classifications mainly make use of five different types, we also segmented the interval in five areas, but this can readily be extended. A very short (VS) interval is defined as an inter-pulse interval shorter than one third of the regular unit length, $\frac{1}{3(n-1)}$. Likewise, a *short* (S) interval can be defined as shorter than two thirds of the unit length, or $\frac{2}{3(n-1)}$, and a *regular* (R) interval as shorter than four thirds of the unit length, or $\frac{4}{3(n-1)}$. Figure 2 gives a clear overview of the labelling of the pulse intervals. The remaining area between regular intervals and the maximum interval length can be divided in two to give *long* (L) and *very long* (VL) pulse intervals. Using this scheme, the name for the left coda in Figure 1 would be labelled *regular short long short* or "R + S + L + S." The coda on the right would be labelled *long very short long very short* or "L + VS + L + VS." Instead of counting pulses, both labels describe the inter-pulse intervals and immediately give an idea of the coda groups' rhythms.

Combining Pulse Intervals—The second part of labelling is the combination of pulses. Obviously, when two consecutive pulse intervals have the same duration and carry the same label, they are combined—for example, *two-long two-short* or "2L + 2S." It is possible, however, that two intervals fall just on either side of a label boundary as

Figure 1. Both 5-pulse codas might be named "1 + 2 + 2" if they were encountered in different studies, even though they follow different rhythms. When found in the same study, the names might be "1 + 2 + + 2" and "1 + 2 + 2," still giving little information about the rhythms and how they can be compared.

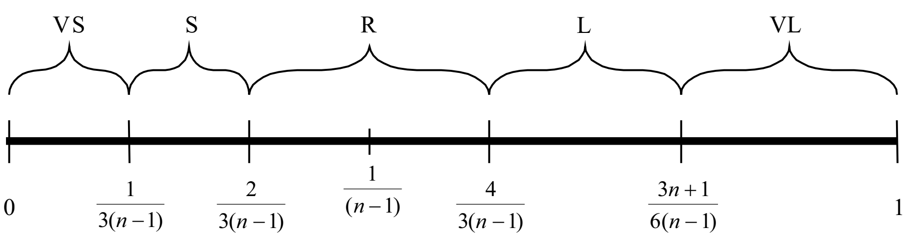

Figure 2. Classification of a normalised pulse interval of an n-pulse coda; the line represents the maximum length of an interval and is divided into five segments (*very short*, *short*, *regular*, *long*, and *very long*), which depend on n. For example, an interval of 0.15 s of a 4-pulse coda would fall between $\frac{1}{9}$ and $\frac{2}{9}$ and be classified as a short interval.

demonstrated in Figure 3 for a 4-pulse coda. On the left side of the figure, the coda is shown with two fast pulse intervals and one very long. On the right side of the figure, the length of the pulse intervals are drawn as the dashed vertical bars, and the short vertical bars mark the label boundaries. While there is no problem labelling the coda as "VS + S + VL," it can be preferred to group pulse intervals when they have similar lengths and label their average duration (as is done with current labelling schemes). Since this protocol aims at removing subjectivity, this needs to be clearly defined. One straightforward method is to use information from the cluster itself and to take into account the standard deviations of the intervals. Then, two pulse intervals are considered to have similar duration if their means lie within two standard deviations of each other, or $\frac{|m_1 - m_2|}{s_1 + s_2} < 1$, where m_1 and m_2 are the sample means and s_1 and s_2 are the sample standard deviations of the intervals. If a third pulse interval, m_3, following m_2 with standard deviation s_3 is also closer than $s_2 + s_3$, then the three pulses are combined. After the intervals are added together, their new combined mean is evaluated, and they are labelled together.

The labelling process is independent of the clustering algorithm, and it cannot be guaranteed that different clusters receive different labels. The quality of any clustering algorithm highly depends on the data, and when the data separate poorly or do not conform to the model used for clustering, the cluster distances may be very small, leading to identical names. Depending on the variances of the clusters, it could be preferred to combine them, but when necessary, the resolution of the labelling protocol can be improved by partitioning it into smaller intervals and dividing the unit length by a factor higher than three. The labelling resolution is limited by the spreading of the data, however, because at some point the characterisation of the average of an interval will no longer be representative for the majority of the intervals as they will fall outside the label interval.

Results

The labelling protocol is demonstrated in Table 1. The codas were ordered by their number of pulses and clustered using a *k*-means method (Hamerly & Elkan, 2003). Codas containing more than six pulses are not listed because we did not have a sufficient number of samples to reliably cluster the data (less than 50 samples per coda type).

Table 1 lists the average values and standard deviations for all intervals and the resulting names for every coda cluster following the described protocol. The five interval types as specified in Figure 2 showed sufficient resolution for these data. For example, the *short* intervals from the 4-pulse codas in Table 1 have standard deviations of 0.043, 0.059, 0.093, and 0.098, while the 4-pulse short interval spans a length of 0.11 s. Further partitioning would result in an interval label that does not represent the majority of the intervals. All pulse interval standard deviations were smaller than the length of the label intervals.

The effect of taking into account the standard deviations to combine pulses can be clearly seen—for example, the 6-pulse coda cluster, "L + 4R," contains a 0.11 interval, which normally would be labelled as *short*. In the context of the interval sequences and standard deviations, however, it is labelled as *regular*.

Discussion

An alternative protocol to labelling coda clusters has been proposed. The protocol aims to avoid subjectivity in the cluster names and uses a systematic approach to assign a name to a coda cluster. The use of a fixed protocol is important because it makes it easier to compare coda groups between different studies. The algorithm makes use of the normalisation of the codas, which implies that the codas are analysed by their rhythm. This rhythmic structure of a coda cluster can then be used to define its label. Since the labelling protocol is independent of the clustering algorithm, there is no guarantee that different clusters will not end up with the same label. This is why it is important to take into account the variance of the coda clusters and especially of the individual intervals. While the resolution of the proposed protocol can easily be improved to cover more types of intervals, lowering the chance of identical names, the value of the increase in detail depends on the variance of the pulse intervals. For our data, the

Figure 3. Combining inter-pulse intervals on a 4-pulse coda; the left image shows the normalised coda, with four pulses and its three numbered inter-pulse intervals. On the right, the labelling definition of Figure 2 is pictured again. The three dashed vertical bars that are added are the numbered inter-pulse intervals of the coda. The third inter-pulse interval is classified as *very long*, but the intervals 1 and 2 almost have the same length. It could be preferred to combine and label them together, depending on the means and variances of these intervals in the cluster.

Table 1. Classification of normalised coda clusters using standardised names; clusters containing a very small number of codas, while labelled here, should not be considered to be a representative group. All values are given in two significant figures.

Class name	Interval means * 10^{-1}(SD *10^{-2})					#
3-pulse codas						859
L + S	7.3(4.4)	2.7(4.4)				782
2R	4.2(6.5)	5.8(6.5)				77
4-pulse codas						170
L + S + R	5.0(5.9)	1.6(4.3)	3.4(7.2)			59
2R + S	3.6(12)	4.9(8.8)	1.5(5.9)			57
3R	3.0(5.3)	3.3(3.5)	3.7(4.8)			38
2S + L	1.6(9.3)	1.4(9.8)	7.0(15)			16
5-pulse codas						117
L + 3R	4.0(6.0)	2.0(6.6)	1.8(6.2)	2.2(7.4)		53
4R	2.3(3.2)	2.4(6.7)	2.4(6.1)	2.9(7.5)		37
F + 3R	0.97(3.8)	2.4(4.8)	3.1(6.3)	3.6(5.7)		27
6-pulse codas						325
L + 4R	3.8(4.1)	1.7(4.8)	1.1(2.6)	1.3(2.6)	2.1(3.2)	258
5R	1.7(3.2)	1.7(2.9)	1.8(2.7)	2.0(3.7)	2.7(6.1)	29
R + 3S + L	2.6(5.6)	1.1(6.1)	1.0(3.5)	1.9(6.5)	3.4(7.4)	18
2VS + R + 2L	0.65(1.8)	0.6(2.1)	2.3(3.2)	3.0(3.3)	3.5(3.2)	17
VS + L + 3R	0.65(6.0)	3.6(5.7)	1.8(10)	1.8(6.4)	2.2(6.0)	3

use of five different interval characterisations was sufficient, and if the detail was further increased, the average value of an inter-puse interval would no longer have been representative for the majority of the intervals within its cluster. Other coda studies also rarely seem to need more than five interval types as they use three to five different types, consisting of regular intervals combined with one or two "plus signs" to indicate long or very long intervals. Unfortunately, we could not directly compare the protocol with other reports due to the lack of published data. Often, the inter-pulse interval variances are missing, and sometimes the interval values are not given either. To assist with the evaluation of the labelling protocol on other data, the Matlab tool used for the analysis in this report is available for download (LAB, 2006).

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