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Article

A Law of Word Meaning in Dolphin Whistle Types

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Abstract: We show that dolphin whistle types tend to be used in specific behavioral contexts, which is consistent with the hypothesis that dolphin whistle have some sort of "meaning". Besides, in some cases, it can be shown that the behavioral context in which a whistle tends to occur or not occur is shared by different individuals, which is consistent with the hypothesis that dolphins are communicating through whistles. Furthermore, we show that the number of behavioral contexts significantly associated with a certain whistle type tends to grow with the frequency of the whistle type, a pattern that is reminiscent of a law of word meanings stating, as a tendency, that the higher the frequency of a word, the higher its number of meanings. Our findings indicate that the presence of Zipf's law in dolphin whistle types cannot be explained with enough detail by a simplistic die rolling experiment.

Keywords: dolphin whistles; semantics; communication; laws of language; Zipf's law; quantitative linguistics

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1. Introduction

Many quantitative laws of human language are known. Some examples are the law of brevity, Zipf's law for word frequencies and Menzerath-Altmann's law [1,2]. The law of brevity states that more frequent words tend to be shorter [1]. Zipf's law for word frequencies states that $f(i)$, the frequency of the i-th most frequent word of a text obeys approximately [1,3]:

$$f(i) \sim i^{-\alpha}$$

where $\alpha \approx 1$ is the exponent of the law. Menzerath-Altmann's law states that the longer a construct, the shorter its components [2]. For the particular case of the length of a word with respect to the length of its syllables, Menzerath-Altmann's law yields that the longer a word, the shorter its syllables. Notice that we use the term law to refer to statistical patterns or tendencies, as is traditionally done in quantitative linguistics and cognitive science, which is different than the stronger sense of the term law used in physics, e.g., Newton's laws of motion.

Despite the many laws of human language that are known [2-4], to our knowledge, only a few have been studied in the context of the behavior of other species [5-8]. Zipf's law has been studied in the frequency of calls of black capped chickadees [5] and in the frequency of dolphin whistle types [6,7]. Recently, the law of brevity has also been reported for the repertoire of surface behavioral patterns of dolphins [8]. The finding of laws of language in other species can be seen as a coincidence due to mere chance, not only because of the small number of species and laws considered but also for the debate on the utility of the presence of Zipf's law in another species [9,10]. However, many cetaceans show some of the most sophisticated cognitive abilities among all mammals and exhibit striking cognitive and social convergences with primates, including humans (see [11] for a review). Here we aim to study if a law of word meaning, i.e. the tendency of more frequent words to have more meanings [12], has any parallel in dolphin whistle types. Quantitative linguistics studies on different languages have clearly shown that number of dictionary meanings of a word and its frequency are positively correlated [4,12,13].

We use the term semantic degree to refer to the number of dictionary meanings of a certain word and contextual degree to refer to the number of behavioral contexts with which a certain whistle type is significantly correlated. Although at present it is technically impossible to study the law of human meanings in another species (assuming that the human notion of dictionary meaning or an equivalent one can be applied in another species), we can study it indirectly from the contextual degree, this degree being a crude approximation to the number of meanings of a whistle type.

The remainder of the article is divided into four sections. Section 2 shows that dolphin whistle type production is consistent with the hypothesis that whistles have some sort of "meaning" in the sense that they are not independent from the behavioral context. Section 3 shows the existence of individuals whistle types with a coherent "meaning" between pairs of individuals. Section 4 shows that more frequent whistle types tend to be associated with more behavioral contexts as more frequent human words tend to have more meanings. Section 5 discusses the implications of our findings for the debate on the relevance of Zipf's law in dolphin whistle types. Some concluding remarks are presented in Section 6. Finally, Section 7 explains the materials and methods employed.

2. Do Dolphin Whistle Types Have “Meaning”?

The “meaning” of whistle types has been previously studied by evaluating behavioral context of whistles in windows of whistle sequences [14]. Here we aim to shed light on the possible “meaning” of whistle types from the behavioral contexts of whistle types, but without focusing on whistle sequences. The data set used was from that used in previous publications [6,7,14-16]. The data set contains information about the whistle types produced by 17 captive dolphins (eight adults and nine infants) and the behavioral contexts in which they were produced. Adults were wild caught, but have been in captivity for more than 10 years. All infants were born in captivity. Behavioral context was recorded for each whistle emitted and Table 1 summarizes the different behavioral contexts used in this study. All the behavioral contexts are from the perspective of the emitter of a whistle type.

Table 1. Summary of the behavioral contexts used.

No.	**Description**
1	Vocalizer aggresses or is aggressed by another adult dolphin
2	Vocalizer disciplines or is disciplined by another dolphin
3	Vocalizer affiliates with another dolphin, often rubbing or contact position
4	Vocalizer involved in sociosexual behavior with another dolphin involving genitals, intromission attempts, etc.
5	Vocalizer socially plays with another dolphin (e.g., play chases, etc.)
6	Vocalizer approaches or is approached by a dolphin other than its mother or infant
7	Vocalizer approaches or is approached by its mother
8	Vocalizer departs or is departed by a dolphin other than its mother or infant
9	Vocalizer departs or is departed by its mother
10	Vocalizer swimming with a dolphin other than its mother or infant (no apparent affiliation or aggression)
11	Vocalizer is swimming with its mother
12	Vocalizer swims alone
13	Vocalizer plays with an object (e.g., fish, toy)
14	Vocalizer orients to hydrophone
15	Vocalizer orients to orcas in another pool separated by a gate

Note that meaning and context are closely related concepts in human language. To see this, consider that many techniques in computational linguistics rely on guessing the meaning of certain occurrence of a word in a text from its context [17]. Words with more meanings tend to appear in more contexts. Many kinds of context can be used: the local context (e.g., the other words appearing in the same sentence) or the global context (e.g., the topic of conversation or the place where it is taking place). Thus, by using contextual information, we are employing crucial information for guessing the meaning of a word and perhaps also guessing the meaning of a dolphin whistle, but *a priori* we do not know if dolphins have an equivalent to word meaning. For this reason, we prefer to use “meaning” for whistle types and meaning (without ‘’) for human words. “Meaning” in the context of dolphins refers to a continuum of possibilities between two extremes: (a) dolphins do not have any equivalent to word meaning and whistles are simply constrained by the context and (b) dolphin whistles have something equivalent to word meaning. Besides, we prefer to stay objective in this article and treat contextual degree (for dolphin whistles) and semantic degree (for human words) as clearly distinct measures although contextual degree in dolphins and the corresponding semantic degree might indeed be strongly correlated.

Table 2. Summary of correlations and anticorrelations between whistle types and behavioral contexts at the three levels, i.e., all individuals, age group and individual, at a significance level of 0.05. ID is the tag identifying an individual dolphin. Within the main column “Number of type-context pairs”, the column “All” is the number of possible type-context pairs (i.e., the product between the values of column “Whistle types” and “Contexts”). “All” is the sum of the values in the columns “Positively correlated”, “Negatively correlated” and “Uncorrelated”. The values in the column “Positively correlated” cannot exceed the corresponding values in column “Occurring at least once”.

				Number of type-context pairs				
Level	**ID**	**Whistle types**	**Contexts**	**All**	**Positively correlated**	**Negatively correlated**	**Uncorrelated**	**Occurring at least once**
All	-	116	15	1,740	51	7	1,682	260
Adults	-	26	15	390	17	2	371	91
	BAY	10	4	40	4	0	36	15
	CHE	11	8	88	3	2	83	26
	CIR	2	1	2	0	0	2	2
	GOR	6	1	6	0	0	6	6
	SAD	12	8	96	7	2	88	29
	SCH	4	4	16	1	1	14	6
	STO	11	9	99	5	0	94	27
	TER	7	3	21	0	0	21	8
Infants	-	98	13	1,274	38	9	1,227	198
	DEL	15	10	150	3	1	146	33
	DES	3	1	3	0	0	3	3
	ECB	5	1	5	0	0	5	5
	LIB	31	1	341	18	2	321	65
	NEP	9	5	45	2	0	43	21
	NOR	39	13	507	12	3	492	76
	PAN	39	10	390	13	3	374	67
	SAM	4	2	8	0	0	8	6
	TAS	9	4	36	1	0	35	14

Following the idea from computational linguistics above, the freedom with which a certain whistle type co-occurs with behavioral contexts can be regarded as being indirectly related to the "meaning" of certain whistle type. A lack of freedom can be manifested in two different ways:

- Positive correlation: a whistle type tending to appear more often in certain behavioral contexts.
- Negative correlation (or anticorrelation): a whistle type tending to not appear in certain other contexts.

Notice that evidence of these positive or negative correlations does not constitute a proof of "meaning" (the problem is a particular instance of the fact that correlation does not imply causality). Correlation with context is a consequence of "meaning" but not a sufficient condition. If we did not find evidence of contextual correlation we could conclude that dolphins whistle types have no meaning at all (assuming that the contexts considered are conveniently defined). If we found them, we could conclude that the hypothesis that they have meaning stands (by now).

For each pair of whistle type and behavioral context we study if the frequency with which they co-occur is:

- Significantly high (positive correlation).
- Significantly low (negative correlation or anticorrelation).

at three different levels:

- Individual (a single dolphin).
- Individuals from the same age group (infant or adult).
- All individuals (both infant and adult dolphins).

Table 2 indicates that statistically significant correlations and anticorrelations between whistle types and behavioral contexts are found at all the three levels. In all cases, the number of negatively correlated type-context pairs never exceeds the number of positively correlated type-context pairs.

3. Consistency on the Context of Use of Whistle Types

Now we aim to determine if different dolphins produce whistle types consistently. To this aim, we define the support of a certain type-context pair within a certain group (all, adults or infants) as the number of individuals in which the pair is (significantly) correlated within that level. Thus, the support is a number between 1 and the number the individuals at that level (type-context pairs with no supporting individual are excluded). Note that the units of support are individuals. Tables 3 and 4 are frequency tables showing the number of positively and negatively correlated type-context pairs, respectively, that have a certain support at each decomposable level. For instance, Table 3 indicates that there are 59 positively correlated type-context pairs that have support 1 (i.e., they are positively correlated in a single individual only) at the level of all individuals, 20 at the level of adults and 42 at the level of infants. In contrast, Table 3 shows that there are 3 + 1 = 4 positively correlated type-context pairs that have support greater than 1 at the level of adults, 0 at the level of adults and 2 + 1 = 3 at the level of infants. The interesting cases are the significantly correlated type-context pairs that are supported by more than one individual because they suggest agreement among individuals.

Table 3. Frequency table of the support of positively correlated type-context pairs within each level at a significance level of 0.05. The units of support are individuals and the units of frequency are positively correlated type-context pairs. The p-value is the estimated probability of obtaining the same value of "Frequency" by "selecting" type-context pairs at random and independently from other dolphins.

	Positively correlated type-context pairs					
	All		**Adults**		**Infants**	
Support	**Frequency**	**p-value**	**Frequency**	**p-value**	**Frequency**	**p-value**
1	59	0.99	20	0.68	42	0.99
2	3	0.097	0	1	2	0.14
3	0	1	0	1	1	0.0042
4	1	6.9×10^{-5}	0	1	0	1

Table 4. Frequency table of the support of negatively correlated type-context pairs within each level at a significance level of 0.05. The units of support are individuals and the units of frequency are negatively correlated type-context pairs. The p-value is the estimated probability of obtaining the same value of "Frequency" by "selecting" type-context pairs at random and independently from other dolphins (see the Materials & Methods section).

	Negatively correlated type-context pairs					
	All		**Adults**		**Infants**	
Support	**Frequency**	**p-value**	**Frequency**	**p-value**	**Frequency**	**p-value**
1	10	0.99	5	0.979499	7	0.99
2	2	0.00074	0	1	1	0.023

As seen in Tables 3 and 4, some type-context pairs are supported by at least two individuals. However, we need to determine which supports greater than two have a significantly large number of positively or negatively correlated type-context pairs (we refer to this number as "frequency" in Tables 3 and 4). It might be the case that the frequency of a certain support, i.e. the number of type-context pairs with this support, is expected from mere chance, i.e. if all dolphins "selected" the pairs to become significantly correlated at random and independently from other dolphins (see the Materials & methods section for the details). As for positively correlated pairs, the only support that has a number of pairs significantly large (with a significance level of 0.05) is support 4 at the level of all dolphins and support 3 at the level of infants (Table 3). As for negatively correlated pairs, the only support that has a number of pairs significantly large (with a significance level of 0.05) is support 2 at the level of all dolphins or infants only (Table 4).

Does the finding of agreement on the context where whistle types are produced by two or more individuals provide evidence that dolphins can communicate successfully? According to Tables 3 and 4, if whistle types were understood with the same type-context conventions with which they are produced, then mutual understanding might be possible at least for certain individuals. However, we need to be cautious for two reasons. First, notice that the agreement found among between different individuals on the behavioral context in which a certain whistle should be or should not produced, could simply be caused by imitating another individual with no communicative goal at all. Second, notice that *a priori*, a direct coupling between production and comprehension is not warranted. Many computer models of the evolution of communication assume that production and comprehension can dissociate [18,19]. Thus, two dolphins may produce whistle types according to the current behavioral context using the same conventions but may not be able to make the inverse step, inferring the behavioral context from the whistle type, even when they share the same private knowledge. It is well-known that a dissociation between production and comprehension, may lead to the following paradox: two communicating agents are able communicate with each other better than with themselves [19]. The extreme situation of this paradox is an agent that cannot communicate with an identical twin [18], although both agents share the same private knowledge. In sum, our findings only show compelling evidence that production is consistent among individuals (possibly conventionalized beyond simple imitation) but it is not warranted *a priori* that production conventions can be understood successfully. Successful communication is supported but not proven by our findings.

4. Dolphin Whistle Types Obey a Law of Word Meaning

Now we turn our attention to the relationship between the frequency of a whistle type frequency and its contextual degree, i.e. the number of behavioral contexts with which it positively correlated. Table 5 shows the Pearson correlation between whistle type frequency and contextual degree for the cases where the Pearson correlation is well-defined (see Materials & methods section). In all these cases except two (NOR and PAN), a positive significant correlation is found at a significance level of 0.05.

Table 5. Summary of the correlation between whistle type frequency and number of positively correlated behavioral contexts. ID is the tag identifying an individual dolphin and *N* is the number of points on which the Pearson correlation *r* was calculated.

Level	**ID**	***N***	**Pearson *r***	**p-value**
All	-	46	0.730	0.0015
Adult	-	14	0.593	0.0055
	SAD	6	0.990	$<10^{-5}$
Infant	-	35	0.947	$<10^{-5}$
	LIB	16	0.996	0.0083
	NOR	11	0.478	0.097
	PAN	11	0.760	0.091

5. Discussion

We have seen that dolphin whistle type production is consistent with the hypothesis that dolphins whistle types have some sort of "meaning". This is a new finding for dolphin whistles, other than the debated signature whistle ([20-22] for review) and research indicating that whistle sequence has some relationship to behavioral context [14]. Furthermore, we have seen that dolphins share, in some cases, the context in which a certain whistle type tends to be or not be produced, which constitutes a prerequisite of successful communication among individuals.

As for the connection with laws of human language, we have found that more frequent whistle types tend to be associated to more behavioral contexts (in almost all the cases where the correlation test was possible), a feature that is reminiscent of a law of word meaning stating, as a tendency, that the higher the frequency of a word, the higher its number of meanings [4,12,13]. The finding of an inverse relationship between frequency and number of "meanings" or number of behavioral contexts is expected from information theory. To see it, consider the interpretation of entropy as a measure of information from standard information theory [23]. Then the information of a set of symbols n whose probabilities are $p_1, p_2,\ldots p_n$ is [23]:

$$H = -\sum_{i=1}^{n} p_i \log p_i . \qquad (1)$$

Notice that H can be regarded as the expected value of -log p_i, i.e., H = E[-log p_i]. If according to standard information theory H is a measure of information [23], then it follows from H = E[-log p_i] that H is indeed an average measure of information and –log p_i is the information of the i-th symbol. In general, if a symbol has frequency p then its information is –log p. Thus, the information of a symbol decreases as its probability (or relative frequency) increases. Consistently, the higher the semantic or contextual degree of a certain item (e.g., a word or a whistle type), the less informative it is, i.e., the lower its information. Besides, this inverse relationship has implications for the scope of information theoretic models of Zipf's law [24-26] departing from the assumption that the frequency of a signal (e.g., a word) is positively correlated with its number of semantic associations (e.g., its semantic degree of its contextual degree). Our findings indicate that this assumption is not only valid for human language but also for dolphins whistle types.

Although the presence of Zipf's law in dolphin whistles [6] has been the matter of a debate on the relevance of this pattern because a simple die rolling experiment may reproduce Zipf's law [9,10], we believe that our findings provide the basis for clarifying the debate. We will argue that die rolls do not reproduce or explain satisfactorily the main statistical results of this article:

1. Whistle production depends on the context.
2. Coordination between individuals (dolphins share the context in which a certain whistle type tends to be or not be produced).
3. Agreement with a law of word meaning (the positive correlation between the frequency of a whistle type and its contextual degree).

To see it, consider that we have only two possibilities: (a) the faces of a die and behavioral contexts are statistically independent and (b) the opposite of (a), namely, the faces of a die and behavioral contexts are dependent somehow. A simplistic example of (b) is obtained when the faces of the die are behavioral contexts.

Under (a), the die rolling experiment is a meaningless source that mimics a meaningful source as human language [9]. If condition (a) is true, then whistle types would be produced regardless of the behavioral context. Thus, no statistically significant type-context correlations would be found, contrary to results number 1–3. Die rolls cannot mimic or explain our statistical results.

Under (b), the die rolling experiment is not a meaningless source that mimics a meaningful source but a possible explanation. Notice that assuming (b) contradicts the central argument behind the die rolling experiment, namely that Zipf's law is not necessarily caused by a meaningful source or that the units upon which Zipf's law is observed do not necessarily convey information [9] (information about the behavioral context in our case). However, we can skip this contradiction concerning the motivations behind the die rolling experiment and focus on the explanatory capacity of the die rolling experiment itself. Notice that it would not be possible to explain result 2 because the die rolling is conceived for the behavior of a single dolphin but not of an ensemble. A possible way of explaining coordination between individuals is that the dolphins sharing the same type-context conventions are subject to identical or similar die rolling processes; but why? Imitation could simply explain it.

Then, what would be a real challenge for a die rolling experiment is to explain results 1 and 3. To this aim, one would need to reformulate the die rolling experiment to make it a valid explanation.

What makes a possible explanation a good explanation is a justification of realism of the model and thus answer some questions like:

- What are really the faces of the die?
- How a combination of faces yields a "distinctive" signal?
- Is it realistic that the faces are statistically independent?
- Why should they be statistically independent?
- …

Notice that in the case of Zipf's law in human words, this has never been satisfied. For instance, some authors have argued that faces would be the letters (or phonemes) making words [27,28] but this is completely unrealistic as words are not produced by constructing words from scratch by combining letters (or phonemes) but by retrieving already existing words (words shared by population of speakers of the same language) and sometimes (only sometimes) inventing new words. Another lack of realism is that letters (or phonemes) are not statistically independent within a word as these die rolling experiments dictate. Letters (or phonemes) combine to form syllables, morphemes,…following patterns that are not arbitrary. Speakers of a language can simply infer that a word is not part of their language just simply by looking at the way letters are being combined. In the case of dolphin whistles, a justification of the die rolling experiment in terms of an explanation has never been provided because the die rolling experiment was never seen as an explanation but as source that would trivially reproduce the data [9].

If a die rolling experiment, at least in the way it is presented so far, cannot satisfactorily reproduce or explain the results on context degree, then which models could be suitable candidates? The law reported in section 4 indicates that we could explain the presence of Zipf's law in dolphin whistle types recurring to information theoretic models [24,25] that assume that the frequency of a signal is positively correlated with its number of semantic associations (see [26] for a critical review of these models).

An important point in the debate about the relevance of Zipf's law in dolphins whistles [9,10] is that in the absence of prior information about the source (e.g., whether it is communicative or not), the law does not allow one to make any inference about the linguistic complexity of the source [9]. Our findings show that we do have prior information in the case of dolphins: recall results 1-3. These facts do not mean that dolphin whistles are equivalent to words but should encourage further research on the possible relationship between whistles types and human language.

We have seen that besides the law of brevity found in the surface behavior of dolphins [8], the behavioral context of dolphin whistles follows the same pattern as a well-known law of word meaning. Furthermore, laws of language are found not only in the behavior of other species [5-8] but also in other natural systems. For instance, Menzerath-Altmann law has been found in the genomes, i.e. the more chromosomes a genome has, the shorter the chromosomes, as the longer a word, the shorter its syllables [29]. The fact that certain regularities of language are found in other natural systems suggests the existence of general principles of organization that are not specific to human language. Besides, the presence of all these laws across species and systems, suggests that a deeper understanding of natural systems can be achieved from our understanding of language and *vice versa*, i.e. a deeper understanding of human language can be obtained through insights from other natural systems.

6. Conclusions

We have seen that the statistical properties of the mapping of dolphins whistle types into meanings is consistent with the hypothesis that dolphins whistles have some sort of "meaning" and that dolphins are communicating through them: whistle type use is constrained by the behavioral context and it can be shown that these constraints are shared by different individuals in some cases. We have found further connections with human language: the pattering of dependence the frequency of a whistle type and its number of contexts is reminiscent of a law of word meaning, something which is expected from standard information theory. These features of communicative systems challenge the claim that the finding of Zipf's law in dolphin whistle types could be the result of a simplistic die rolling experiment. Instead, the ubiquity of Zipf's law in natural communication systems could be explained by general principles of communication based on information theory. Statistical patterns offer a unique chance to a mutual understanding of language and other natural systems through a unified approach.

7. Materials and Methods

We used whistle types and their corresponding behavioral context from the data set in [6,7,14-16]. Occurrences of whistle types whose behavioral context was not available were excluded from our analysis.

Whistle types in this data set are obtained by classifying whistles using a contour analysis technique [30]. The similarity between this automatic classification technique and the way dolphins categorize whistles is not known. However, this automated technique was developed based on the way dolphins imitate computer-generated whistles [31,32]. The robustness of this technique is a matter of debate [22,33]. However, as seen in the preceding sections, this automatic classification technique is useful in terms of shedding light on the communicative function of dolphins whistle types and finding connections between laws of human language and the communication system of dolphins. Notice also that dolphin whistles were automatically classified and independently from the behavioral context or contexts in which they were produced [15,16,30]. This way, any significant association between a whistle type and a behavioral context cannot be attributed to the whistle classification technique.

We used Fisher's exact test [34] to determine if a whistle type is significantly correlated positively (right-tailed test) or negatively (left-tailed test) with a certain whistle type from their frequency of co-occurrence (Tables 2–4). Fishers's exact test has been used in computational linguistics to detect collocations: pairs of words that co-occur with a frequency that is greater than expected from chance, i.e., positively correlated words [35].

In Tables 3 and 4, it is necessary to determine if the number of type-context pairs with a certain support is larger than expected from chance (the relevant supports for a hypothesis of coordination between individuals are those greater or larger than two). We considered the case that each dolphin forms (positively or negatively) correlated pairs by choosing type-context pairs uniformly (with the only constraint that a pair can be chosen only once) till the number of (positively or negatively) correlated pairs of that individual according to Table 2 is reached. We assume that *a priori* that the individual has to choose among all the different types and contexts at the level under consideration. For instance, if we are assessing the significance of the number of positively correlated pairs with a certain support at the level of infants, the dolphin PAN has to choose type-context pairs from $98 \times 13 = 1274$ possible pairs (see Table 2) till 13 pairs are formed (PAN has 13 positively correlated pairs). If the same dolphin is evaluated at the level of all dolphins, then he has to choose type-context pairs from $116 \times 15 = 1740$ possible pairs (Table 2). Following this procedure, we can estimate numerically the probability p that y or more type-context pairs have support x from dolphins of a certain level (all, adults or infants) by repeating the assignation of pairs to each dolphin at a certain level many times (10^4 in our case). This probability p is the p-value shown in Tables 3 and 4.

When studying the correlation between frequency and number of contexts (Table 5) it is important to notice that a necessary condition for a well-defined Pearson like correlation between two variables [34] is that the values for each variable are not constant (otherwise a null standard deviation does not give a finite correlation). Besides, we made the conservative decision of excluding the whistles types with contextual degree zero (as if they had no meaning at all) because words without meaning are not considered in the law of word meaning reviewed in the introduction section. Notice that the semantic degree of function words is operationalized as the number of dictionary entries (e.g., [4]) and therefore do not have semantic degree zero.

This restriction causes data sets with maximum contextual degree equal to one to be excluded since the relationship between frequency and contextual degree turns out to be constant and thus well-defined correlations cannot be obtained. In our data set, a maximum contextual degree above one was only found in three infants (LIB, NOR, PAN) and one adult (SAD). For this reason, the maximum support on Table 3 does not exceed four.

The p-values for the unilateral Pearson correlation test in Table 5 where obtained from a permutation test over 10^8 uniformly distributed permutations. This kind of test has the benefit of preserving the distributions of the two variables involved. We chose the Pearson correlation statistic for simplicity. Notice that the use of a Monte Carlo technique frees us from the constraints the parametric Pearson correlation test [34]. Although a Spearman rank correlation test might be considered more convenient *a priori* (estimating p-values through permutations as in the Pearson correlation test), it was excluded because it gives less statistically significant correlations between frequency and contextual degree than the Pearson correlation test. Table 6 shows a comparison of the results obtained with the two statistics. In particular, the Spearman rank correlation fails to find a significant correlation for the dolphin SAD. The best statistic is the one that allows one to reject the null hypothesis that there is no positive correlation between frequency and contextual degree in as many cases as possible. For this reason, Table 5 shows only the results with the best statistic, i.e., Pearson correlation, between the two that we tried.

Table 6. Summary of the correlation between whistle type frequency and number of positively correlated behavioral contexts. ID is the tag identifying an individual dolphin and N is the number of points on which the Pearson correlation r and the Spearman ρ were calculated.

Level	**ID**	N	**Pearson** r	**p-value**	**Spearman** ρ	**p-value**
All	-	46	0.730	0.0015	0.470	0.0016
Adult	-	14	0.593	0.0055	0.651	0.0082
	SAD	6	0.990	$<10^{-5}$	0.655	0.17
Infant	-	35	0.947	$<10^{-5}$	0.426	0.00084
	LIB	16	0.996	0.0083	0.615	$<10^{-5}$
	NOR	11	0.478	0.097	0.403	0.091
	PAN	11	0.760	0.091	0.512	0.091

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