Exploring the linguistic capacities of bottlenose dolphins: the processing of recursive syntax

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We explore two main categories of research that have been done on the linguistic capacities of dolphins: the analytic approach and the interactive approach. Both have their own advantages and complement each other. We conclude that dolphins have been shown to use long-range correlations in their own language and to process different types of syntax in a sophisticated manner. When confronted with anomalous syntax, they search backward and forward in sequences for familiar grammatical structures while taking into account the semantics. We conclude that dolphins display an understanding and generalisation of syntactic properties like category-based rules, argument structure and closed-class items. Building on these results, we ask the question how much further their capacities to process complex syntax reach. What has not been researched extensively is their understanding of recursive syntax. In an attempt to explore the complexity of their linguistic capacities, we take the syntax we know they are able to process as a starting point and extend it towards a recursive syntax. We propose a method to research the ability of dolphins to comprehend this novel type of syntax. To do this, we identify three possible cases of recursive syntax and two types of novelty to be taken into account.

Introduction

Since the 80's there is a lot of research going on, regarding the linguistic capacities of dolphins (Herman, Wolz, & Richards, 1983; Herman, Richards, & Wolz, 1984; Herman, 1986, 1987; Herman, Kuczaj, & Holder, 1993; Herman & Uyeyama, 1999; Herzing, 1996; Herzing, Delfour, & Pack, 2012; Janik & Sayigh, 2013; King & Janik, 2013; Kohlsdorf, Gilliland, Presti, Starner, & Herzing, 2013; Sayigh, Esch, Wells, & Janik, 2007; Schusterman & Gisiner, 1988; Kako, 1999; Ferrer-I-Cancho & McCowan, 2009, 2012; Ferrer-I-Cancho, Lusseau, & McCowan, 2016; Ryabov, 2016; Frasier et al., 2017; Amundin, Eklund, Hållsten, Karlgren, & Molinder, 2017). In this paper we explore some of the different types of research that has been done, and explore how far the linguistic capacities of dolphins go by extending the research on syntax. Even though we are far from understanding what dolphins actually communicate about, there are some conclusions we can draw from the almost 40 years of research on their linguistic and mental capacities. To name a few: Dolphins are able to learn artificial languages and generalize the syntax of sequences up to five items (Herman et al., 1984); they are able to create abstract representations of objects that are not dependent on modality (Herman, Pack, & Hoffmann-Kuhnt, 1998); they use signature whistles to identify each other (King & Janik, 2013; Sayigh et al., 2007; Janik & Sayigh, 2013); they recognize themselves in a mirror (Reiss & Marino, 2001); their whistles follow Zipf's law, beyond what can be expected from random signals (Ferrer-I-Cancho & McCowan, 2009); their whistles show statistical significant long-range correlations, extending up to the 4th previous whistle. (Ferrer-I-Cancho & McCowan, 2012). These conclusions justify the conclusion that dolphins are highly conscious and intelligent animals that possess a complex language. But how complex is their language exactly? Can we identify the different nuances of their linguistic capacities and explore the borders of these capacities? Is a recursive syntax part of what they can learn? In this paper, we lay out a map of the different conclusions and approaches so far and use these as an foundation to explore their capacity for recursive syntax.

Two approaches

We found two main approaches towards the research on dolphin language. We characterise the first approach as the 'analytical approach', the second as the 'interaction approach'.

Analytical approach

A part of the more recent research can be categorised as the 'analytical approach' and has its focus on what Ferrer-I-Cancho et al. (2016) identifies as a combination of quantitative linguistics and information theory. He tries to avoid the type of research that can be critiqued for having an 'anthropocentric bias' because it takes the linguistic capacities of humans as a starting point, while using fuzzy qualitative definitions that are almost impossible to operationalize objectively. In this approach, the research typically focuses on the 'native' language of the dolphins, observing their spontaneous acoustic signals in combination with their natural behavior. In this way, Ferrer-I-Cancho and McCowan (2012) shows their language to have long-range correlations, and specific whistles to be correlated with specific behavioral contexts (Ferrer-I-Cancho & McCowan, 2009).

Long-range correlations in whistle sequences. Human language is know to contain long range correlations between words (Montemurro & Zanette, 2011; Montemurro & Pury, 2002). If we encounter a certain word in a text, certain words have a higher probability of showing up further on in the sentence. Showing long-range correlations to exist in dolphin whistles has consequences for the complexity of their language. It would also argue against the hypothesis that regularities in dolphin whistles like Zipf's law can be considered as random sequences with no more meaning than the regularities in a die rolling experiment (Suzuki, Buck, & Tyack, 2005). Ferrer-I-Cancho and McCowan (2012) performed statistical analysis on a set of dolphin whistles from 17 different dolphins. In his paper, he uses a information theoretical measure to quantify the conditional mutual information between two whistles, given a certain distance d. The same approach has been used to quantify correlations in research on DNA, texts and music (Ferrer-I-Cancho & McCowan, 2012). To get a grip on the likelihood of the correlations as compared to a random process, the data is randomized in two different ways. In *global randomization* the whole collection of sequences is randomized, in *local randomization* all the pairs of whistles at a certain distance d are randomized. After a meta-analysis of his results, the conclusion of his analysis is that for the global randomization the number of dolphins showing correlations up to a distance of $d = 2$ are statistical significant. For local randomization the number of dolphins with significant correlations is statistical signification for distances up to $d = 4$. This means that it is unquestionable that dolphin whistles have long-range correlations that can not be explained as random phenomena but instead follow a syntax with long-range correlations.

Disadvantages of the analytical approach. While results as obtained by Ferrer-I-Cancho and McCowan (2012) are valuable and shed some light on the complexity of dolphin whistles and the syntax that generates their whistle sequences, it does not tell us anything about the semantics of their communication. The bottleneck in this approach is that the analytical approach needs much larger datasets to really unravel the complexity of dolphin language, combined with a need for better hardware to capture and process the signals (Amundin et al., 2017). Even though the recent technical progress is promising for this approach, the current studies that explicitly hope to unravel what the dolphins communicate about (e.g. the paper of Amundin et al. (2017)) are still at the stage of research proposals. The obvious advantages of the analytical approach are its objectivity, combined with a direct focus on the 'native' language of the dolphins. But the disadvantages are the analytical and technical complexity, without the short term perspective of giving anything more than highly abstract results. These disadvantages are the reason we decided to focus on the second approach.

Interaction approach

The research that can be categorised as the 'interaction approach' starts much earlier in time (around the 80's) and focuses on what the dolphins can learn in interaction with humans. For example, Herman et al. have done a lot of interaction research with dolphins that are held captive and are trained with the purpose of performing in entertainment shows (Herman et al., 1983, 1984; Herman, 1986; Herman et al., 1993). They typically learn the dolphins an artificial language and let them execute instructions in a seawater tank. Denise Herzing et al. did their research with wild dolphins (Herzing, 1996; Herzing et al., 2012; Kohlsdorf et al., 2013), typically engaging with the dolphins in games the dolphins want to play. To explore their capacities, they developed an interface for two-way communication between the human researchers and the dolphins. While both research groups do valuable research, Herman et al. display a more explicit focus on syntax. This makes their type of research more suitable for our goal of identifying the level of complexity of their language. The ability of a dolphin to learn a certain syntax does not necessarily imply that the dolphins actually use this type of syntax in their own language. However, it does make it more likely that they are familiar with a syntax of comparable complexity and it does have implications for their intelligence.

Comprehension of sentences. Herman et al. published their extensive results on their experiments with two bottlenose dolphins in which they explored the ability of dolphins to generalize syntax (Herman et al., 1984; Herman, 1987). In their experiments they use two dolphins, living in outdoor seawater tanks. One dolphin was trained with an artificial language composed of computer generated sounds, the other dolphin was trained with a sign language composed of hand and arm gestures of the trainer. Both dolphins were trained with a vocabulary of about 40 items, where the vocabulary can be categorised as (a) *objects* in the tank (b) *actions* (c) *modifiers* that function as adjectives (d) *control* and function words. The dolphins are trained with two types of syntax, with a sentence length up to 5 combined items: 1. *nonrelational* 2. *relational*. The nonrelational syntax is composed of the categories (MODIFIER) + OBJECT + ACTION, where the modifier is optional. For example, the sequence RIGHT PIPE TOUCH would mean the dolphin had to select a pipe on the right among multiple pipes in her basin and touch it with her tail. The relational syntax is composed of the categories OBJECT + OBJECT + RELATION or OBJECT + RELATION + OBJECT, depending on the dolphin that was trained. These relational 3-item sentences could be extended to 4-item or 5-item sentences by adding an optional MODIFIER before each of the objects. The relational syntax differentiates between two thematic roles: (1) indirect objects (IO) (2) direct objects (DO). The indirect objects are the destination objects, the direct objects are the objects that should be acted upon. In the OBJECT + OBJECT + RELATION syntax, the first object is the indirect object, the second object is the direct object. For example, using the OBJECT + OBJECT + RELATION syntax, the sentence WATER RIGHT BASKET FETCH would mean that the dolphin had to take the basket on the right (the second object with a modifier and thus the DO) and transport it to a water pipe. To prove that the dolphins actually understood the syntax, and not just simply memorised the sequences, Herman et al. tested the ability of the dolphins to generalize the syntax. This was done with five different approaches: (a) lexical novelty (b) structural novelty (c) semantic reversibility (d) reporting missing objects (e) conjoined sentences.

Lexical novelty is defined as a sentence were known words were used for the first time in a familiar syntax. They used procedures to control for nonlinguistic cues and observer bias. In the most strict procedure, the sentences were selected quasi-random, with the constraint that all known syntactic form were included without repeating sentences. The novel sentence was embedded with familiar sentences, in a way to no word from the new sentence was used in the previous five sentences. During these tests, all known objects were put in the tank and allowed to drift. In this strict category, the performance of the dolphins ranged from 50% tot 77%, depending on the dolphin and the type of syntactic structure. These results are far beyond what would be expected by chance ($p < 0.0001$).

Structural novelty is defined as giving the dolphins new syntactic forms without training. For example, when the dolphins were trained with MODIFIER + OBJECT + RELATION + OBJECT, the syntactic structure OBJECT + RELATION + MODIFIER + OBJECT would be considered novel when presented for the first time. The dolphins responded correctly to the first instance of these sentences, and performed between 53.8% and 76.7% on additional sentences over a several month period. These performance levels as well exceeded chance expectations ($p \leq 0.0001$).

Semantically reversible sentences are a subset of the first two categories of novel sentences. In this subset, the sentence could have been reversed and still be meaningful. The performance on this subset is close to the performance on all novel sentences with scores between 54.2% and 65.9% and an overall $p < 0.0001$.

Reporting missing objects is defined as giving the situation were multiple objects are present in the tank and a two word sentence refers to a missing object. If the dolphin notices the absence of the referred object, it could press a paddle to indicate the absence. The performance on the absence test was 80.9% with $p \leq 0.001$.

Conjoined sentences are an example of recursive syntax. Herman et al. gives the rule $S \rightarrow S(\text{and } S)$. Herman et al. generated a set of two conjoined sentences with the syntax OBJECT + ACTION + OBJECT + ACTION and tested their response. They describe tests with 15 conjoined sentences and conclude that "in the majority of the cases Phoenix [the name of the dolphin] responded to two conjoined sentences requiring that two responses be performed to a designated object, by performing two responses to that object". However, there were different types of responses with different strategies, and Herman et al. (1984) restrains from given a statistical measure but recommends 'further study' instead.

Responses to anomalous sentences. In later research, Herman et al. (1993) tested one of the dolphins that was used in the study by Herman et al. (1984) for the dolphin's response to anomalous sentences. They specifically examined responses to anomalous relational sequences as defined above, where the normal syntax would be O(bject) + O(bject) + R(elation) for a relational sequence or O(bject) + A(ction) for a nonrelational sequence. Two types of functionally different objects were used in the construction of anomalies, namely transportable (T) and non transportable (static, S) objects. For example, using a nontransportable object as the indirect object of a sentence (e.g. SSR) would not make sense from a semantical perspective. The experiments were embedded in daily, 40 minute training sessions with contained 17 correct sequences each. 5 out of 7 weekly sessions contained 2 anomalous sequences. The dolphin responded in two different ways to these experiments: (a) rejection (b) repairing by taking a subset. *Rejection* occurred most commonly to the SSR, SSA and SSRA sequences. SSR sequences are semantically impossible, because they ask for a non transportable object (S) to be transported. This indicates that the dolphin can discern anomalous syntax from normal syntax, because novel sentences were never rejected when they followed normal syntax. If a transportable object (T) was embedded in the anomaly (e.g. SSTR or SSTA) rejection was rare. The dolphins tended to repair the sentence by creating a valid subset like STR or TA. Herman et al. (1993) concludes "the primary basis for rejection was thus inappropriate semantic relations rather than syntactic violations". In repairing the syntax, the dolphin never violated the thematic role of the object by inversing the direct object with the indirect object. The dolphin also discriminated with regards to the final item of a sequence. STTR, STSR and SSTR dominantly resulted in a relational response, were STTA, STSA and SSTA never did. This implies that the dolphin processed the entire sequence before organizing a response. Herman et al. (1993) further concludes that the dolphin is "apparently searching both backward and forward in the sequence for familiar grammatical structures as well as semantically meaningful relationships".

Syntactic properties. Kako (1999) reviews the research done by Herman et al., identifying four 'core properties of syntax'. These are (a) discrete combinatorics (b) category-based rules (c) argument structure (d) closed-class items.

Discrete combinatorics indicate that words, when combined, do not blend their meaning but rather recombine in ways prescribed by the syntactic laws. The simple fact that the dolphins are able to correctly interpret sequences of words indicates that the words retain their individual meaning. Kako (1999) thus concludes that dolphins must be familiar with this property.

Category-based rules indicate that a syntax describes how words of a specific category should be combined. A consequence of this is that we can hear a complete novel sentence (that might even be meaningless), but we still can judge the sentence to be a syntactically lawful sentence. This not only gives us the ability to produce novel sentences, but it also facilitates the understanding of these sentences. Kako (1999) gives the example of telling someone he bought a new computer program called *Gorp*. Because we know that this word is a noun, we can build sentences like "Gorp crashed my computer". According to Kako (1999), the findings of Herman et al. regarding the ability of the dolphins to process novel sentences (Herman et al., 1984; Herman, 1987) indicates that the dolphins have this syntactic property as well. The dolphins are able to generalize the syntactic laws to a degree they can interpret novel sentences, and even exceptions to the rules.

Argument structure dictates the syntactic structure that certain verbs should follow. There are two necessary criteria that need to be addressed: 1. the amount of arguments for a verb 2. thematic roles assigned to syntactic positions. The amount of arguments dictates how many arguments a verb needs, to make sense. For example, the verb 'kiss' needs two arguments: someone that is giving the kiss, and someone receiving the kiss. When someone says "The boy kissed the girl", the first argument ("the boy") has the thematic role of kisser, the second argument ("the girl") has the thematic roll of being kissed. Switching the positions would alter the semantics of the sentence. To evaluate if the dolphins possess knowledge of argument structure, Kako (1999) looks at the outcome of the experiments were the dolphin reacts to anomalous sentences (Herman et al., 1993). Because the dolphin sometimes rejected the anomalous sentences and sometimes repaired them, Kako (1999) concludes the reactions of the dolphin are 'inconsistent' when Kako tries to evaluate the knowledge of the number of arguments. To his idea, we would have to know "whether these strings struck Ake as ungrammatical [. . .] Unfortunately, we cannot know how these sequences "felt" to Ake [. . .] Her knowledge of argument number thus remains uncertain." We disagree on this conclusion with Kako. The dolphin actually was consistent in her reactions, because she rejected the semantically impossible sentences and repaired the sentences that had more than the required amount of arguments by taking a legal subset. To repair a sentence by taking a subset, the dolphin had to have both an idea of the semantics and of the proper amount of arguments. Herman and Uyeyama (1999) actually responds to Kako, in which they argue along the same lines: the dolphin rejection or repair is not 'inconsistent' but actually reflects semantic and syntactical insight. On top of that, the dolphin shows it searches each sequence both backward and forward for syntactically and semantically correct sequences, showing both knowledge of argument number and thematic role. With regards to the knowledge of thematic roles, Kako (1999) takes the "remarkable accuracy" on maintaining the thematic roles in sequences were reversal would have been possible as proof of a syntactical knowledge of thematic roles.

Closed-class items are one of two lexical types: those that carry primarily meaning (open-class items) and those that primarily provide structure (closed-class items) (Kako, 1999). This distinction is of interest, because there are differences between the two classes regarding the age of acquirement, event-related brain potentials during on-line processing and selective disruption with brain injury (Kako, 1999). Nouns and verbs are typically considered to be open-class items, while prepositions, numbers and inflections of verbs are typically considered closed-class items(Kako, 1999). In his evaluation, Kako (1999) argues that even though items in the sign language the dolphins were trained with like OVER, UNDER and THROUGH have English equivalents that are considered closed-class items, we still can not conclude from this that the dolphins actually possess knowledge of closed-class items. He states that "relational sentences with OVER/UNDER/THROUGH are really conjoined sentences in disguise". Herman and Uyeyama (1999) responds to this conclusion by arguing that, even though explicit prepositions are not present, "the terms FETCH and IN contain implicit prepositions in that they code for location" and that "IN is itself a closed-class item, in that it describes a relationship and not a singular action". In addition to this, Herman and Uyeyama (1999) argues that dolphins show understanding of pointing gestures functioning like the demonstrative *that*. The dolphins also showed to be able to semantically process conjunctions, because they were able to distinguish between AND (where two sentences are conjoined) and ERASE (where all preceding gestures should be ignored). We find the arguments of Herman and Uyeyama (1999) convincing in arguing that the dolphins have knowledge of closed-class items.

The presence of recursion

In the generative linguistic tradition, the property of recursion has received a lot of attention. Chomsky has been a main proponent of the importance of this property, explicitly introducing this term in his influential text *Syntactic Structures* (Chomsky, 1957). In a later publication, Hauser, Chomsky, and Fitch (2002) suggested that recursion may be "the only unique human component of the faculty of language". This claim has provoked a lot of criticism, both on the claim itself (Pinker & Jackendoff, 2005; Parker, 2006) and on the definition of recursion by Chomsky being imprecise (Tomalin, 2011; Lobina, 2014). Even though we avoid giving a precise definition of what recursion means, we will give precise definitions of syntax that we regard as an example of recursive syntax. Regardless of the overall definition, our proposed syntax is an extension of the complexity of syntax we currently know they are able to process. Research by Herman et al. showed that dolphins are able to comprehend conjunctions (Herman et al., 1984; Herman, 1987). In their paper, Herman et al. (1984) argue that a conjunction can be regarded as a form of recursion when looked at as a grammatic rule in the form of $S \rightarrow S(\text{and}\, S)$. As we have not been able to find any further research with regards to the ability of dolphins to comprehend recursion, we decided to explore this topic in more depth.

Research question and hypothesis

Our research question is if, and to what extent, dolphins are able to process different types of recursive syntax. To formulate a hypothesis, we will first define what we regard as an example of recursive syntax. We take as a starting point the relational syntax OBJECT + OBJECT + RELATION that was used by Herman et al. (1984), and rewrite the syntax in a recursive style:

1. $S \rightarrow S + S + r$
2. $S \rightarrow o$

S is defined as a sentence, r is a relational verb and o is an object. The o and r are lowercase to denote a terminal item. With this recursive syntax, we are able to generate different types of sentences with a upper limit of five items. The first case is:

$$\begin{aligned} S &\rightarrow S + S + r && \text{by rule 1} \\ &\rightarrow (S + S + r) + S + r && \text{by rule 1} \\ &\rightarrow o + o + r + o + r && \text{by rule 2} \end{aligned}$$

and the second case:

$$\begin{aligned} S &\rightarrow S + S + r && \text{by rule 1} \\ &\rightarrow S + (S + S + r) + r && \text{by rule 1} \\ &\rightarrow o + o + o + r + r && \text{by rule 2} \end{aligned}$$

These cases differ in the distance d for the long-range correlations between the items. We use the same convention as Ferrer-I-Cancho and McCowan (2012), where $d = 1$ indicates adjacent words and $d = 2$ indicates words that are one word apart from each other. We find a length of $d = 4$ for the second case, where the dolphin has to correlate the o on the first position with the r on the last position. In addition to this , the second case contains an anomalous sequence of three objects. This makes the first case, while still requiring recursion to process the meaning of the sentence, less complicated in terms of long-range correlations and additional anomalous syntax. The first case does require the dolphin to process a long-range correlation of $2 \leq d \leq 4$, when the first three positions have to be correlated to the r on the fifth position. The research of Ferrer-I-Cancho and McCowan (2012) showed that dolphins use long-range correlations in their own communication, at least for ranges up to $d = 2$ with a conservative interpretation and up to $d = 4$ with a less conservative interpretation. Taking into account these results, we do not expect dolphins to have problems with these long-range correlations. With regards to the length of the sentences, did the research from Herman et al. (1984) show that dolphins are able to process sentences of at least five items long. A third case, with a length up to seven items, is:

$$\begin{aligned} S &\rightarrow S + S + r && \text{by rule 1} \\ &\rightarrow (S + S + r) + (S + S + r) + r && \text{by rule 1} \\ &\rightarrow o + o + r + o + o + r + r && \text{by rule 2} \end{aligned}$$

This case exceeds the upper length of the sequences Herman et al. (1984) used, possibly exceeding an upper limit in the processing capabilities of the dolphins. On the other had, this case might be less confusing than the second case because it does not contain an additional anomalous syntax of three adjacent o's. It does extend the length of the long-range correlations to $4 \leq d \leq 6$. In addition to this, the third case contains two conjoined legal sentences $(o + o + r)$. A response where the dolphins would execute the two conjoined sequences while ignoring the last r would not directly rule out their possible understanding of recursion, but could be viewed as an intelligent guess regarding the intentions of the trainer. Imagine humans being subject to the linguistic experiments of intelligent aliens: while trying to make sense of new sequences of gestures, humans might also react in different ways while trying to make sense of familiar patterns being combined in recursive patterns.

We hypothesize that the dolphins will be able to learn and generalize at least one of these three cases, where the first case seems to be the simplest and thus the most likely case to be learned.

Methods and procedure

Our proposed method is similar to that used by Herman et al. (1993). The experiment will take place in an outdoor seawater tank with the same objects used in the experiment by Herman et al. (1984). This way we can expand on the linguistic knowledge already present, without the need of building up a complete new repertoire of gestures. Our experiment will be integrated in the normal training schedule of the dolphins. We will assume this to be the same schedule as described by Herman et al. (1993), with daily sessions with 17 sentences.

Selection of participating dolphins

Because dolphins, and dolphins with a training in an artificial sign language in particular, are quite rare (especially when compared to the availability of first year students) we will have to lower our standards with regards to the amount of participating dolphins. Actually, we would regard ourselves to be quite lucky if we would get access to even a single nearby dolphin that has been trained with the necessary syntax to build our experiment on. The nearby 'Dolfinarium' actually has dolphins trained with a certain type of sign language, but at this point we do not know anything about the details of their training or acquired syntax.

Linguistic elements

We will use eleven objects (six transportable, five non-transportable). The six transportable objects are 1. frisbee (FRISBEE) 2. basket (BASKET) 3. surfboard (SURFBOARD) 4. pipe (PIPE) 5. ball (BALL) 6. hoop (HOOP). The five non-transportable objects are 1. any of the windows in the tank (WINDOW) 2. another dolphin (PHOENIX) 3. a water stream (STREAM) 4. a person sitting on the wall of the tank (PERSON) 5. an underwater speaker (SPEAKER). For every experiment, all items will be present in the tank, functioning as possible distractors. There are two kind of relational terms: 1. bring the second object to the first object (FETCH) 2. place the second object inside or on top of the first object (IN). Even though the dolphins are familiar with modifiers like LEFT or RIGHT to distinguish between two similar object, we will not use modifiers in an attempt to minimize the length of the sentences.

Two experimental classes

We will follow the approach of Herman et al. (1984) with different types of experimental classes. Both classes will use operant conditioning after the dolphin has executed the intended actions. If the dolphin understands the sequence correctly it will be rewarded with fish and social reinforcement such as hugs and hand clapping. If the dolphin responds differently from what was intended by the sequence, no reward will be given. The trainer simply signals the dolphin to return by splashing the water or slapping the tank wall.

Class I will follow strict procedures for the control of cues. Novel sentences will be inserted in a quasi-randomized list of familiar sentences. Constraints will be that no sentence is repeated, and 30% of sentences that could be possibly generated will be kept as a test subset to be used for testing lexical novelty after the dolphins are considered to have mastered the syntactical novelty. The other 70% will be regarded as the training subset for syntactical novelty. All objects will be present in the tank and allowed to drift. There will be one trainer standing on a platform located outside of the tank, wearing opaque glasses during the instructions. This way, the trainer can not give nonverbal cues. The trainer gets his instructions from a supervisor which does not communicate with the dolphin, but only gives the instructions to the trainer. There is also one blind observer who doesnt know which instructions were given to the dolphin. The blind observer describes the dolphin responses.

Class II allows for nonverbal cues to guide the responses of the dolphin, including things like pointing gestures or suggestive context. Class II will only be used in later stages of the training, after the response of the dolphins to a novel syntax has been judged under Class I conditions. Class II results will not be useful to evaluate the generalisation of syntax, but it can be used to establish a solid familiarity with the intentions behind a certain sequence. After the dolphin has become familiar with a certain syntax, training under both Class I and Class II conditions, we will be able to test the generalisation of the familiar syntax with regards to lexical novel sentences under Class I conditions, using the test subset that was kept apart initially.

Two types of novelty

Similar to Herman et al. (1984), we will discern two types of novelty. We will start our experiments with what we regard as the simplest type of recursive sequence: $o{+}o{+}r{+}o{+}r$. Presenting the dolphin with this syntax can be regarded as a case of syntactical novelty, which will be trained under Class I conditions. We will use Class I conditions exclusively for a period of 4 months. We will not be able to use the complete training subset, because there are about 1320 possible sentences[1] that can be generated under the constriction that only the first object can be both a transportable and non transportable object. After this period, we will move on to training under Class II conditions with the training subset. After the dolphin shows to be able to execute this syntax with the help of extensive cues, we will start testing lexical novelty with the (now familiar) syntax under Class I conditions.

[1]With 11 possible object at the first location, and respectively 6 and 5 items at the second position (5 because we don't use modifiers for objects and thus can use every transportable object just once in a sequence), we can generate a maximum of $11*6*2*5*2 = 1320$ possible combinations. Because some combinations might be nonsensical from a semantic perspective, this number is a rough upper limit for the amount of possible sentences

Three types of recursion

The two types of novelty will be tested with all three types of recursion. As mentioned before, we will start with $o+o+r+o+r$. After this syntax has been completed for both the syntactic and lexical novelty, we will move on the more complex cases of both $o+o+o+r+r$ and $o+o+r+o+o+r+r$. The same procedure will be used as with the first case of recursion.

Examples of sentences and expected behavior

We calculated there to be a maximum of 1320 possible combinations with the first case of recursion. For obvious reasons of brevity, we will not list all possible sentences and their expected behaviour here. However, we will give two examples of possible sentences and the expected behavior.

1. BASKET + BALL + IN + FRISBEE + IN
2. STREAM + PIPE + FETCH + FRISBEE + IN

The expected behavior for the first sentence will be to put the ball in the basket and then continue to put the frisbee in the basket with the ball. The expected behavior for the second sentence will be to bring the pipe to the water stream and then continue to put the frisbee in the stream with the pipe. When there are more baskets or streams present, the dolphin will be free to choose any of those for his first action but will have to put the frisbee in the basket containing the ball, or the stream containing the pipe.

Expected results

In the experiments of Herman et al. (1993), the dolphins showed a wide variety of possible reactions to novel and anomalous syntax. Based on those results, we expect the dolphins at first to try to repair the anomalies by searching for a familiar subset. This will be the $o + o + r$ subset in all cases. This means they will then be left with an anomalous subset, which they could either simply ignore, try to fix by including any of the other objects in the tank, or by using a recursive interpretation. If the dolphins are able to learn the recursive sequence we expect the dolphin to be able to learn a recursive interpretation. Even when the dolphins won't directly have a correct response with syntactical novelty under Class I conditions, we will still regard the dolphins to be able to process this type of recursive syntax if they show the ability to generalize this syntax for lexical novelty under Class I conditions. We think this is reasonable, because it can easily be imagined for humans to have a wide range of responses to an artificial language. An recursive interpretation of a novel sentence, without any instruction, couldn't even be expected from every human that someone would test under Class I conditions.

Evaluation of performance levels

We can evaluate the outcome of the experiments in two different ways. The first type of evaluation is a purely quantitative evaluation. In this approach, we can simply divide the reaction of the dolphins in two types of reactions: correct and incorrect. These reactions can be evaluated for both syntactical and lexical novelty, with regards to all three cases of recursion. This generates six possible categories, where the dolphin could obtain a different score in each category. However, we will take positive results on at least one of the recursive cases for at least the lexical novelty as a positive confirmation of our hypothesis that the dolphins will be able to process a recursive structure. We think this is reasonable because a negative result on the syntactical novelty could have another explanation as explained by our thought experiment with humans under the same condition. To establish a performance level for the quantitative approach, we will use the same approach as used by Herman et al. (1984) and described in detail in his paper : a binomial distribution model combined with a finite-state model of the syntax to derive the probability of a correct response by chance. The second type of evaluation includes a more qualitative analysis of the results. Even when the dolphins wouldn't react strictly as intended, they could still display intelligent strategies while parsing the sequences. The dolphins showed a sophisticated approach towards anomalous sentences in the research of Herman et al. (1993), so we expect the dolphins to show the same sophistication while trying to solve the syntactical riddles we provide them. We expect the dolphins to try different strategies while trying to decipher the syntactic novelties. The analysis of these strategies might generate new hypotheses of their linguistic capabilities. We do expect them to find out the intended recursive interpretation and to be able to generalize this type of syntax, but it is hard to predict at what point the dolphins will find out what the intended meaning of the syntax is, especially because we will present the novel syntax without any clues for the interpretation. Whatever their approach may be, we will still be able to analyse their approach with regards to the strategies they will apply. In the experiments of Herman et al. (1984), the dolphins gave a correct reaction to syntactical novelty even the very first time they were presented with a certain new syntax. The speed at which different dolphins would learn the recursive interpretation would tell us something about their familiarity with recursion, in combination with the difficulty of the category of recursion. The amount of errors the dolphins would make on a certain syntax can be expected to diminish over time. The slope of this curve for the different categories will thus give information about their learning process. We expected the first case of recursion to have the steepest learning slope, the other two cases being more complex in terms of long-range correlations and anomalous syntax.

Discussion and conclusion

A positive result on at least one of the recursive cases, for at least the lexical novelty, would confirm our hypothesis that dolphins are able to generalize a recursive syntax. However, this would not directly indicate that they use recursive strategies in their own language. If the dolphins would pick up this syntactical novelty with the first case of recursion under Class I conditions, this would increase the probability that they are familiar with recursive syntax, but will not be a definitive conclusion. Another remark could be that the proposed syntax does not have any structural indicators for the recursion. Consider an example of recursion in English:"Take the ball and put it in the basket, and put the frisbee in that." Here we use the word 'that' to indicate that the ball and the basket should be considered as a new object where the frisbee should be put in. It might be useful to extend the recursive syntax with structural indicators comparable to the English 'that' to see if this makes the instructions easier for the dolphins to interpret. This could be a topic for follow up research. To find out if the dolphins actually use recursion in their own language, we would at least need to use an analytical approach towards their language. With a machine learning approach and a lot of acoustic data, we might be able to fit recursive models to their natural communication. Still, it would be difficult to create an exact definition of recursive patterns, because these patterns should allow for different words in every layer of recursion, meaning we would need to decipher the semantics of their language before we can draw any conclusions about recursion. We would probably first need to make some steps forward in deciphering their vocabulary to get some grip on their semantics. Ferrer-I-Cancho and McCowan (2009) showed that certain "whistle types tend to be used in specific behavioral contexts", which can be a first step towards obtaining some sort of a dolphin lexicon. However, as pointed out by Amundin et al. (2017), it is "likely that much of dolphin-dolphin communication concerns states and aspects of dolphin life which are difficult to observe and may be near impossible for humans to conceptualize". For example, how would we conceptualize the fact that dolphins can identify and object that is being 'sonically illuminated' by another dolphin (Herman & Uyeyama, 1999)? Or even the overall experience of echolocation? Or the fact that they have 'uni-hemispheric sleep', where only one hemisphere sleeps while the other is awake (Rattenborg, Amlaner, & Lima, 2000)? We might hopelessly be convicted towards an anthropocentric bias, regardless of even our most objective analytical approach. On the bright side of things, dolphins seem to enjoy the two-way communication with humans (Herzing, 1996; Herzing et al., 2012; Kohlsdorf et al., 2013). This means we might still be able to create some sort of Rosetta Stone for dolphin language in the near future to probe their lexicon and native syntax, even though we might not be able to conceptually understand everything they are talking about.

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