Cognitive Task Factors Affecting Bubble Production in Bottlenose Dolphins (*Tursiops truncatus*)

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Abstract

During their time spent underwater, cetaceans have the ability to produce underwater bubbles. Over the years, the literature developed a general ethogram for these bubble behaviors, enabling them to be studied more systematically. In more recent years, notions of these behaviors have valence and reflecting cognitive and affective states have emerged. This study observed bubble production behaviors from seven Atlantic bottlenose dolphins (*Tursiops truncatus*) as they engaged with a cognitive task with a clear success/failure outcome. We observed both the types of bubble behaviors that occurred, as well as when during the task the behaviors occurred. Our data suggests that in the context of this task, bubble behaviors were more likely to occur in the success condition, and varied amongst individuals in both the types of bubbles and when they occurred. Further observational studies specifically looking at the valence of these bubble productions can shed light on their adaptive functions.

Introduction

Whether intuitive or not, the notion that our breath is connected to our cognitive, emotional, and affective state has become harder and harder to ignore in recent years (Sarkar, 2017). Whether by passively noting your own shortness of breath in a stressful situation, or by actively practicing mindful practices such as meditation, there is something to be said about our ability to attend to our breath to regulate our cognitive and emotional experiences. It should be noted that breathing is unique in that it is one of the few physiological behaviors that is both under voluntary and involuntary control, paving way for connections to physiological, cognitive, and affective factors (Sarkar, 2017).

In studying the underlying mechanisms of human behavior, it is not uncommon to turn to other non-human animals to comparatively study their cognition in order to gain a better understanding of our own experiences. Out of all non-human animals, dolphins often remain at the forefront of the conversations due to their unique, highly social, and intelligent nature (Herman, 2010). They seem to have evolutionarily diverged from the rest of the mammalian lineage over 55 million years ago, most notable in that they spend most of their time underwater (Pearson, 2011). However, some researchers consider dolphins to converge with non-human primates in their intelligence, complex social lives, and unique acoustic communications, making them the perfect candidate to study comparative behavior and infer potentially reflected affective/internal states from the emergent behaviors (Herman, 2010; Pearson, 2011).

Of the mammalian class, dolphins are regarded as unique in that they spend most of their time underwater, while voluntarily coming up to the surface for air and exhaling through their blowhole. While underwater, dolphins can also expel air, resulting in some form of bubble emission that is visual to the human eye, as well as to conspecifics. While these bubble productions have been studied to some extent, more research is needed to assess the cognitive and affective implications of their occurrences.

Background

Early accounts in the literature regarding cetacean bubble production often note these behaviors as an emphasis for other co-occurring behaviors given that bubbles are visually salient in nature (Moreno & Macgregor, 2019). Over the years, more studies began looking specifically at the function of these bubble behaviors, producing enough observational accounts to develop a general ethogram for these behaviors in both captive and wild settings. There are, for example, some interesting reports of bubble nets to aid in prey capture in the wild (Leighton, Finfer, & White, 2005), suggesting that voluntarily producing these bubbles in the wild serve as an advantageous tool for survival. However, the majority of accounts have been generated in captivity, involving animals at various degrees of human-enculturation. For example, dolphins have been reported to manipulate bubble rings for play (Marten, Shariff, Psarakos, & White, 1996), produce bubble bursts as an indicator of surprise/excitement/curiosity (Delfour & Marten, 2001), and/or of aggression (Baker & Herman, 1984), and create bubble streams/trails concurrent with vocalizations (McCowan & Reiss, 2001). Other notable studies that have specifically focused on bubble behaviors suggest potential communicative aspects (Herzing, 2000; Pryor, 1990), as well as reflections of internal/affective states (Alexander, Abrahams, & Clark, 2021).

In general, these behaviors have been operationally defined and categorized into four main bubble types: bubble bursts, bubble rings, bubble streams, and scant bubbles (see Table 1).

The study conducted by Alexander, et al., (2021) is one of the most recent studies, and their findings add a new component to the discussion of bubble production - cognition and inferred affective state. In other words, they directly investigated the potential existence of a correlation between bubble production in Bottlenose dolphins and their cognitive function (and thus inferred affective state). The authors conducted a study that recorded any bubble behaviors (particularly bubble bursts) while the subjects were engaging in a defined cognitive task. They were able to cautiously conclude that bubble bursts in particular were most likely linked to positive affective states in relation to the task, and moreover likely having no physiological/respiratory function. They also suggested that bubble bursts may be associated with early judgment of the task, as almost all of the bursts recorded occurred during the initial phases of the task, with little to none occurring as the task progressed. However, given the lack of a success/failure outcome in the cognitive task's design, the authors call for more investigation in a more clear and controlled setting to confirm this relation (Alexander et al., 2021).

This study is an attempt to redress this success/failure limitation by observing animals under clear conditions of cognitive task success and failure in the context of a Match-To-Sample task design. More specifically, this study aims to find any evidence that may support Alexander et al., (2021) findings that bubble production could be associated with positive affective states in relation to a task's success/failure condition. Additionally, this study will investigate any individual differences in regards to bubble production to see if past literature is congruent to the findings in this study.

Military Relevance - IACUC

Atlantic bottlenose dolphins (*Tursiops truncatus*) are essential assets to the U.S. Navy Marine Mammal Program, with their high level of performance on Navy tasks being vital. Investigating ways to determine positive affective states in these animals may provide more insight on how to continue to care for them at the high standard that the Navy maintains. If the data points to bubble production reflecting affective states, which may be seemingly linked to cognitive task engagement/success, this can shed light on further cognitive welfare measures and cognitive enrichment task designs for the future (Clegg et al., 2017).

Materials and Methods

1.1 Subjects & Setting

The subjects in this study were a part of the U.S. Navy Marine Mammal Program. Seven Atlantic bottlenose dolphins (*Tursiops truncatus*), aged between an estimated 10-40 years, participated. The subjects included three males and four females, housed separately by sex. General research sessions occurred weekly Friday - Monday between 13:30 and 18:30. All research sessions for this study were undertaken with one individual at a time and run by the trainers in the Dolphin Cognition Lab, UCSD.

1.2 Cognitive Task Design and Procedure

The cognitive task used in this study was a basic Match-to-Sample test. In this task, the subject is first presented with a sample object, and then with two alternatives, one of which matches the initial sample. After viewing and echolocating on the sample, the animal is required to touch the matching alternative to receive its reward.

A 48”X30”X30” Box apparatus with a PVC frame was used for presenting the objects underwater. The Box is covered in black neoprene to ensure that the objects presented inside are both visually and acoustically opaque, until revealed by a trainer. It contains three doors that can be opened by the trainer to provide visual and echoic access to its contents.

Objects are categorized visually as black, gray, or white; the echoic properties (respectively) being metallic, wooden, and air-filled. Nine objects were used (three of each type) and trials were presented in pseudo-random order. That is, within a given session, three objects were involved, in all possible combinations of alternatives, with the position of the correct alternative (right or left) the same for no more than two trials in a row.

The task itself has one trainer hold the animal in a horizontal position at the surface, parallel to the deck, oriented towards the box. That is, once the animal is oriented towards where the Sample will be presented, the door to the box is opened by the trainer and the Sample is dunked underwater in the box. Once the animal echolocates on it (confirmed by the hydrophone in the pen), the Sample is removed, cuing the animal to seek the match presented at the opposite end of the pen.

When seeking the match the animal encounters two options, one being the Sample (correct), and one being the Alternative (incorrect). In regards to the clear success/failure outcome of this task, the animal must physically touch the Sample object in order to succeed on the trial. If successful, secondary reinforcement (a trainer’s whistle) followed by a primary reinforcement (food reward) is given by the trainer. This sequence follows the basic tenets of operant conditioning. If the trial fails, the animal is given a Least Reinforcing Stimulus (LRS) and sent back to the trial’s start position.

In this particular Match-To-Sample training protocol, each session consisted of twelve consecutive mixed trials.

1.3 Behavioral Data Procedure

Observations were conducted from above the water. Given the Navy's constraints on video recording, the description of each session was continuously audio recorded using a Sony PX Series digital voice recorder. Each session was individually recorded by an observer. Within each session, behaviors were recorded using all-occurrence sampling. Observers coded for the presence/absence of bubble behaviors, for the type of behavior (see Table 1), and when during the trial the behavior occurred (see Table 2).

For coding the type of behavior observed, observers would verbally record the instantaneous moment that a behavior would be seen by saying the descriptive name of the behavior (see Table 1). In other words, the presence of a behavior is verbally recorded, with the absence of a recording inferring the absence of a behavior.

To systematically assess when a behavior occurs during a trial,, each trial was operationally divided into four zones that followed the temporal progression of a trial (see Table 2). These zones were labeled as the Approach, Evaluation, Choice, and Return, and are intended to capture the dolphins' behaviors when they were not directly under control of the trainer.

The Approach zone begins as soon as the animal is cued to go seek the match and begins their swim path from their original station to the opposite end of the pen. It ends once the animal's rostrum reaches the last ⅓ of the enclosure, entering the Evaluation zone. This zone is defined as the phase in which the animals begin to attend to the two objects, hence evaluating their choices. The Evaluation zone ends and the Choice zone begins at the moment they make their choice - i.e. when they physically come into contact with either object. Once the trainer provides the appropriate signal based on the success/failure of the trial (i.e. presence/absence of a whistle tone), the Choice zone ends. The animal is then cued by the trainer to return to the start position. The Return zone begins when the animal is given the cue by the trainer to swim back to the start position, and ends when they reach the control point at the present station.

In regards to the audio recording, as the animal enters each new zone, the observer notes this by audibly clicking a pen into the mic of the recorder. The Approach zone was distinguished by two clicks of the pen in order to distinguish each beginning of a new trial for later transcription. Once the animal reaches the Choice zone and either succeeds or fails at the trial, the observer also verbally notes whether the trial was correct or incorrect (see Table 2).

1.4 Data Transcription Procedure

The audio recordings were hand transcribed into coding sheets by the observers (see Table 4). With a total of three observers, each observer received about three days of training for the behavioral procedure. Inter-Observer-Reliability (IOR) tests were then performed before any initial data was taken to ensure observational agreement and replicability. Another IOR test was conducted at the end of collecting data to ensure that the observers were not straying from the initial protocol. Across both IOR tests and three observers, an averaged Cohen's Kappa of 0.85 was achieved, suggesting substantial agreement in regards to all aspects of the observations.

Table 1.

Descriptions of behaviors coded in this study

Behavior	**Alternative Names**	**Description**	**Citation**
Bubble Burst	Bubble Cloud, Underwater Blowing	Large singular bubble or cloud of bubbles	Delfour & Marten, 2001; Baker & Herman, 1984; Moreno & Macgregor, 2019
Bubble Ring	Bubble Torus	Air ring that slowly surfaces	Marten et al., 1996; Moreno & Macgregor, 2019
Bubble Stream	Bubble Trail, Whistle Trail, Bubble blow, Bubble Column, Bubble Train	Small bubbles produced in a dynamic stream	McCowan & Reiss, 2001; Moreno & Macgregor, 2019
Scant Bubbles	Blowhole Drip	Small single bubbles	Moreno & Macgregor, 2019

Table 2

Description of zones

Zone	**Begins**	**End**
Approach	Subject leaves the present station and begins swim path to the choice station	Subject reaches last third of pen, oriented at the objects
Evaluation	Subject reaches last third of pen, oriented at the objects	Subject makes their choice by physically touching an object
Choice	Subject makes their choice by physically touching an object	Subject is given appropriate reinforcement by trainer based on +/- condition
Return	Subject sent back to the present station	Subject is at the present station

Results

A total of 1180 trials were recorded, with a total of 852 behaviors observed over the course of this study (see Table 3). Across all subjects, three of the four types of bubbles were consistently observed, with marked individual variability (see Table 4). Across all subjects, behaviors occurred in each zone, but with varying frequencies across individuals (see Figure 2).

Table 3

Summary of Total Observed Bubble Production

Subject	Sex, ~ Age	Total Trials	Success Rate (%)	Total Observed Behaviors/Total Trials
A	M, ~15	213	52%	0.7887
B	M, ~11	228	51%	0.7192
C	M, ~10	213	49%	0.3099
D	F, ~30	204	53%	1.1421
E	F, ~40	156	49%	0.6474
F	F, ~30	166	49%	0.7289
G	F, ~40	156	45%	0.0577

*Given that Subject G produced a disproportionately small amount of bubbles in relation to total trials (<6%), they were removed from the subject pool for any further analysis.

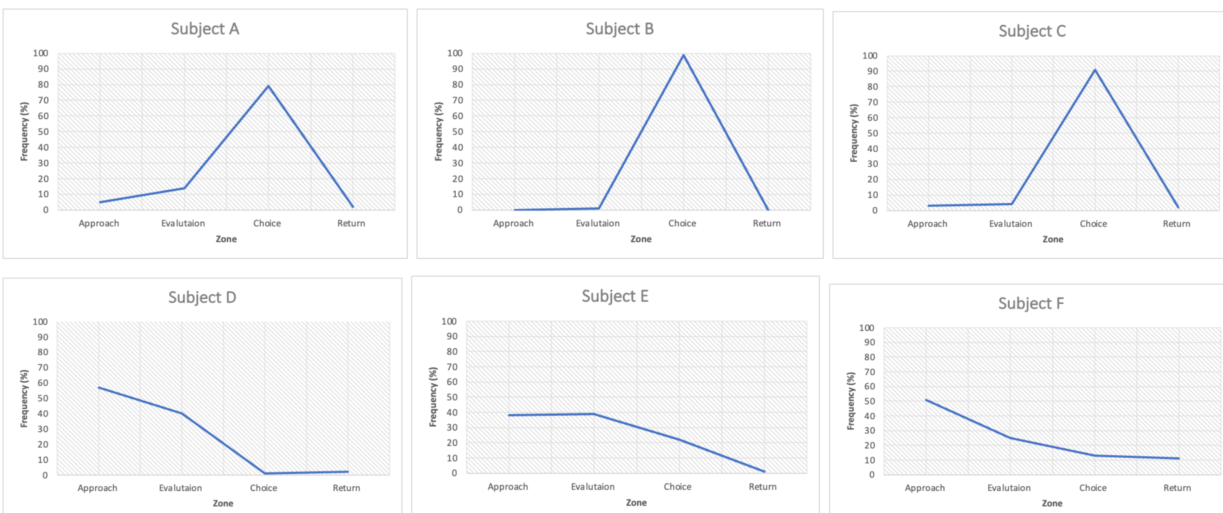
Table 4

Frequency (% out of total) of Occurence of Each Behavior Type

Subject	Sex, ~ Age	Burst	Ring	Stream	Scant
A	M, ~15	2%	0	54%	44%
B	M, ~11	0	0	41%	59%
C	M, ~10	0	0	62%	38%
D	F, ~30	50%	1%	48%	1%
E	F, ~40	61%	0	19%	20%
F	F, ~30	54%	1%	33%	12%

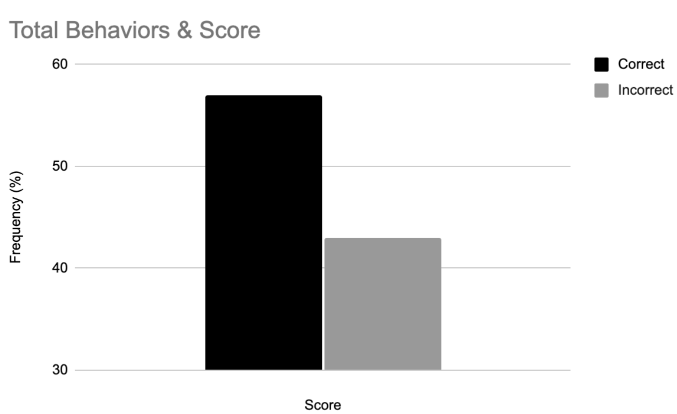
Figure 1

Frequency (% out of total) of When During the Task Behaviors Occurred



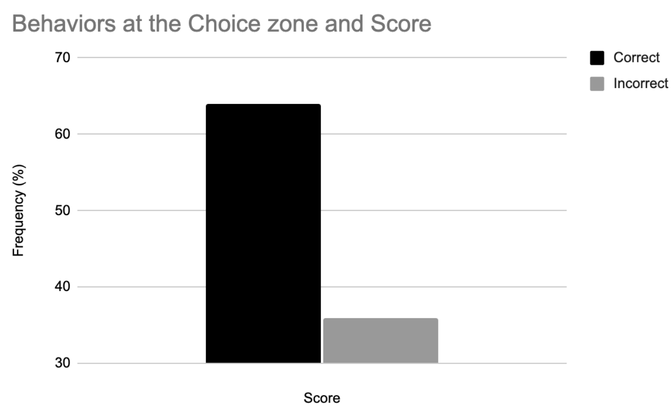
Statistical Analyses

1.1 Success/Failure Condition



In looking at the aggregated counts of total behaviors in the success/failed condition, an overall effect was found for the success condition and total behaviors ($t = 2.4703$, $p = 0.015$). No significance was found in regards to whether the type of bubble produced had any effect on the outcome of the trial (success/failure).

1.2 Total behaviors in relation to zones

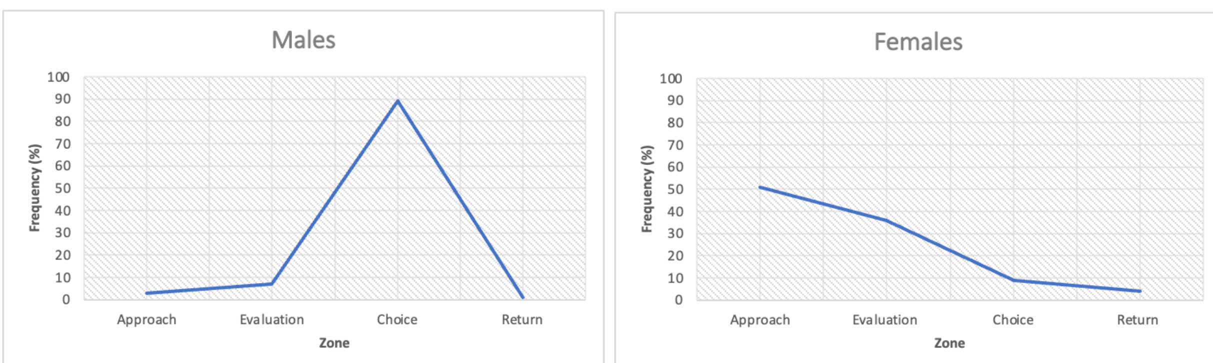


An overall effect was found between total observed behaviors at the Choice zone and the success condition ($t = 2.7388$, $p = 0.012$). When looking at sex differences, both the male and females showed an overall effect between behaviors and success/failure condition at the Choice zone (males: $t = 2.8472$, $df = 11$, $p = 0.01588$; females: $t = 2.7388$, $df = 23$, p-value = 0.0117).

Discussion

Figure 2.

Summary of Male vs. Female Behavior Frequency (%) in each Zone



1.1 Bubble Production - Individual/Age/Sex Differences

Previous literature suggests that bubble production may vary amongst individuals (Moreno & Macgregor, 2019). The current data supports this claim, as well as presents some age/sex differences in regards to both the types of bubble behaviors produced, and when they occurr during the task. However, it is imperative to note that given the subject pool, age and sex are confounded in that the males are an estimated 10-20 years younger than the females. As a result, these differences may concern maturity rather than gender.

In regards to type of bubbles, the males tended to produce more streams and scant bubbles (with almost no bursts), while the females tended to produce more bursts and streams (with very few scant bubbles) (see Table 4). This variability, specifically in regards to the scant bubbles, was initially surprising as a previous study found that scant bubbles were produced more often by females than males (Moreno & Macgregor, 2019). However, given the confounded age sex differences, and the fact that scant bubbles have also been reported to occur more in juveniles than adults, these results may be congruent with the literature. (Moreno & Macgregor, 2019).

In regards to when, during the task, bubbles were produced, an interesting trend arises between the males and females, suggesting that the time during the task is also a factor for bubble production (see Figure 2). Males tended to produce most of their behaviors towards the end of the task, and most specifically at the Choice zone. This Choice zone henceforward will be referred to as the task completion zone, as each trial ends once they make their Choice. Meanwhile, the females produced bubbles more often at the beginning of each trial (in the Approach and Evaluation zones).

The females' data follows similar findings in the Alexander, et al., (2021) study, in that bubble bursts in particular were found to occur earlier in the task rather than later. In this study, females tended to produce more bubbles in the Approach and Evaluation zone (i.e. earlier on during the task), and did not produce many at the actual task completion phase. This finding as well as the females having over 55% of their total bubble behaviors to be bubble bursts is similar to Alexander, et al's (2021) claim that the bubble bursts may suggest early judgment of the cognitive task, which then infers general positive interest and engagement with the task itself.

1.2 Bubble production - Positive/Negative Valence

In following up on Alexander, et al. 's (2021) issue of whether success/failure at the cognitive task is linked to bubble production, our finding that behaviors occurred significantly more often during the success condition, is promising. Additionally, finding significance despite individual/sex/age differences was also reassuring. Having a clear success/failure condition for future studies will continue to aid in assessing the valence of these bubble behaviors.

1.3 Bubble production in relation to Task Completion and Reinforcement Factors

With the animals varying in both types of bubbles produced, and when they were produced in relation to the task, it is important to acknowledge the human components of this cognitive task, specifically at the task completion zone. With both a secondary and primary reinforcement systematically being given to the subjects at the end of each trial, there are sure to be reinforcement factors present that affect the behaviors that emerged.

For instance, when looking at the task completion zone for the males (see Figure 2), we can see a general trend across the three individuals that point to most bubble production occurring as soon as they complete the task. This, combined with the data that males produced mostly scant bubbles, aligns with past literature that scant bubbles may occur more often in high arousal contexts, especially involving human interaction (Moreno & Macgregor, 2019). Given the operant conditioning used at this facility, it may be that the scant bubbles, found in the task completion zone for the males, may point more to general excitement of completing a task rather than perceived cognitive success at the specific task.

It is also important to note that the animals' success rate on Match-To-Sample was averaged to about 51%, suggesting that, at this stage of their training, succeeding and failing may be due to chance. An alternate explanation for the above may be that the animal is simply anticipating the reward and merely reacting to the trainer's whistle as a result. A more minute behavioral procedure would be required to assess whether the production of the bubbles upon task completion occurred before or after the trainer's whistle.

Conclusion

This study provides an observational account of the valence of bubble production in Atlantic bottlenose dolphins (*Tursiops truncatus*) in the context of a specific cognitive task. Although there is limited generalizability given the small subject pool, findings from this study regarding positive affective states in relation to these bubble behaviors were promising, suggesting that further studies should continue to investigate the valence of these behaviors in different contexts. A larger number of human participants in the future would allow confounds of trainer bias to be addressed as well, and provide the basis for a more clear discussion of the reinforcement factors involved with this study.

For future analysis, a Mixed Random Effect Model would be more optimal to assess the repeated measures of this study, as well as a Chi-Squared Goodness of Fit analysis to investigate whether these findings may be representative of a larger population.

In regards to other potential functions of bubble behaviors, such as communicative aspects, future studies that involve dyadic interactions and fine tuned underwater acoustic recordings may shed light on past literature that suggests that bubble streams co-occur with whistles in order to communicate with a conspecific (Herzing, 2000; Pryor, 1990).

Interesting future studies might also entail continuing to follow this intuitive notion that our attention (whether involuntary or voluntary) to our breathing and respiratory control may serve as a regulation tool that can affect our cognitive and affective experiences. Thus, studying the emergent behaviors in a positive/negative valence lens would allow us to begin to make inferences about an individual's internal state. In both humans and non-humans, continuing to study how physiological, cognitive, and affective experiences may be intertwined can allow us to better understand the evolutionary origins, functions, and valence of these behaviors.

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