

Acoustic Characteristics of Bubblestream-Associated Whistles Produced by Atlantic Bottlenose Dolphins (*Tursiops truncatus*) During the First Thirty Days of Life

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Abstract

Bottlenose dolphins (*Tursiops truncatus*) have been observed to produce whistles coincident with bubblestream emissions from the blowhole. Use of bubblestreams concurrent with whistles by calves could function for vocalizer recognition prior to the development of a calf's signature whistle. We observed bottlenose dolphin calves regularly producing bubblestreams with whistles and whistle-squawks during their first month of life. While vocalizations with bubblestreams may differ from whistles without a bubblestream, the former's prominence during the observed calves' first 30 days suggests a potentially important facet of calf acoustic development. This study focused on whistles and whistle-squawks that occurred concurrently with bubblestreams by four bottlenose dolphin calves during their first 30 days of life with the goal of better understanding the early emergence of whistle-type vocalizations. Simultaneous video and acoustic data facilitated assessment of whistle-type vocalizations (i.e., whistles and whistle-squawks) that coincided with a bubblestream emission from a focal calf. The calves' whistle rates (per hour) were highest in Days 21 to 30 compared to Days 0 to 10 and 11 to 20. None of the focal calves developed their stereotyped signature whistle contour (as confirmed after 2 years of age), yet results showed some evidence of repetitive contour emissions during the first 30 days of life. Whistle-squawks were produced significantly more frequently than whistles as the calf aged. Whistle duration and the frequency range significantly increased over time. These data suggest that whistle production begins as early as the first days of life and that the prominence of the chaotic characteristic typical of calf tonal vocalizations persists throughout their first month. Further, whistle-type vocalizations are better able to span longer durations and reach both higher and lower frequencies as a calf develops.

Key Words: Atlantic bottlenose dolphin, *Tursiops truncatus*, bubblestream, whistle-type vocalizations, whistles, whistle-squawks

Introduction

Acoustic signals allow bottlenose dolphins (*Tursiops truncatus*) to maintain contact with conspecifics in visually occluded waters (Caldwell et al., 1973; Tyack, 1997). These vocalizations relay information about individuals' identities, locations, and motivations to reunite (Smolker et al., 1993; Janik & Slater, 1997, 1998; Kuczaj et al., 2015). Typically, vocalizations produced by adult bottlenose dolphins include narrowband whistles, echolocation clicks, and burst pulses, each of which consists of specific spectrographic contour patterns (for review, see Jones et al., 2019). Bottlenose dolphins have the ability to produce two sound types simultaneously (i.e., biphonations) using both pairs of bursa/phonic lips (Caldwell & Caldwell, 1967; Cranford et al., 1996; Cranford, 2000; Cranford & Amundin, 2004) that function unilaterally, independently, and simultaneously (Ridgway et al., 1990).

Biphonations are the simultaneous emission of any two vocalization types. For example, vocalizations comprised of two independent fundamental frequencies (Wilden et al., 1998; Fitch et al., 2002) have been broadly investigated and identified in spotted dolphins (*Stenella frontalis*; Herzing, 2000; Kaplan et al., 2017), killer whales (*Orcinus orca*; Schevill & Watkins, 1966), false killer whales (*Pseudorca crassidens*; Murray et al., 1998), manatees (*Trichechus* sp.; Mann et al., 2006), mysticetes (e.g., humpback whales [*Megaptera novaeangliae*]; Morris, 1986), and terrestrial species (e.g., Pygmy marmoset [*Cebulla pygmaea*]; Elowson et al., 1998). Another type of biphonation is characterized by the simultaneous production of tonal and broadband burst-pulse sounds commonly referred

to as whistle-squawks (see Caldwell & Caldwell, 1967; Reiss, 1988; Herzing, 1996; Killebrew et al., 2001; Kaplan et al., 2017). Whistle-squawks are often produced by young calves (e.g., Reiss, 1988; Caldwell et al., 1990; McCowan & Reiss, 1995; Killebrew et al., 2001; Favaro et al., 2013; Kaplan et al., 2017) and are potentially a result of their morphology or underdeveloped acoustic system, muscular control, or the early development of the phonic lips (Reiss, 1988; Killebrew et al., 2001; García de los Ríos y Loshuertos et al., 2021).

Neonate bottlenose dolphins can produce individually specific, stereotyped signature whistles that are rarely fully developed before 3 months of age (Caldwell & Caldwell, 1965, 1979; Caldwell et al., 1990; Sayigh, 1992); and in some cases, calf whistles may not become stable until sometime during the second year of life (e.g., McCowan & Reiss, 1997). Stereotypy is a common characteristic of signature whistles and is found in shared and non-signature whistle types (e.g., Jones et al., 2020). Neonate bottlenose dolphins practice vocalizations by overproducing various whistle segments prior to producing stereotyped (i.e., a consistent frequency and amplitude modulation pattern), adult-like whistles (Caldwell & Caldwell, 1979; Tyack & Sayigh, 1997).

Vocal development in dolphin calves is critical for survival. As calves develop and gain mobility, they become more likely to venture away from the mother's side, and the mother's ability to recognize her calf's calls may be essential for reunions between the two (Tyack & Sayigh, 1997; Sayigh et al., 1999; Cook et al., 2004; Mello & Amundin, 2005; Kuczaj et al., 2015). Calf whistling likely broadcasts their identity or position to the mother and may facilitate the mother's approach or induce other responses from their mother based on the calf's state (e.g., fear, distress) (McBride & Kritzler, 1951; Smolker et al., 1993; Mello & Amundin, 2005; Gnone & Moriconi, 2009). Bottlenose dolphin calves produce whistles, some of which coincide with the emission of a bubblestream from the blowhole (McCowan & Reiss, 2001; Fripp et al., 2005; Morisaka et al., 2005a, 2005b). Bubblestreams may be used as a visual cue associated with a whistle and may denote which dolphin is vocalizing, which could be useful when observing vocal calves. Although whistles concurrent with bubblestreams likely do not fully represent a calf's whistle repertoire (McCowan & Reiss, 2001; Fripp et al., 2005), this subset of a calf's vocal behavior warrants more investigation. Initial studies of calf whistle behavior revealed similar whistle types between bubblestream and non-bubblestream whistles (McCowan, 1995; McCowan & Reiss, 2001; but also see Fripp et al., 2005).

Fripp et al. (2005) documented that bubblestream-associated whistles were not a representative sample to describe the entire dolphin calf whistle repertoire. Still, they suggested that bubblestreams added emphasis to the associated whistle (e.g., increased arousal level). That said, previous investigations similarly found a large proportion of bubblestream-associated whistles during the first month of life (see McCowan & Reiss, 2001; Fripp et al., 2005; Morisaka et al., 2005a, 2005b). These findings warrant further investigation of bubblestream-associated vocalizations in bottlenose dolphin calves. Thus, this study's focus is to describe the ontogeny of whistle-type sounds produced in association with bubblestreams in viable dolphin calves throughout their first 30 d.

Methods

Four Atlantic bottlenose dolphin calves resident in three managed care facilities (Dolphins Plus Marine Mammal Responder, Dolphins Plus, and Island Dolphin Care in Key Largo, Florida) were observed during their first month of life, with video and acoustic recordings collected. Each mother-calf pair was housed with other conspecifics (minimum of three), and these social structures remained stable for the duration of the study. Video data were collected underwater between July 2010 and October 2012 via an all occurrence, focal-animal sampling protocol while subjects were in visual range of the video recording, with each calf as a focal subject (Altmann, 1974) during on session (training) and off session (non-training) periods (Table 1). To account for variation in focal hours, data were standardized by rate per hour. Data collected for each sampled mother-calf pair occurred independently as calves were born at different times and locations.

Materials and Apparatus

A Canon G9 (12.1 mega pixels) and Canon G12 (10.0 mega pixels with HD) (audio calibrated by Canon every other year) digital camera in respective underwater housings, Canon WP-DC21 and Canon WP-DC34, were affixed to custom monopods and used for underwater recordings. Each camera's microphone sampled audio at 44.1 kHz (stereo setting with equal sample rate across both channels; 16 bit) with a consistent apparatus sound artifact at ~17.5 kHz. For this study, all video recordings had time-synched audio, which allowed researchers to determine the precise start time of a bubblestream and the accompanying vocalization when the animals were in video visual range. Routine placement of cameras and hydrophones in the lagoons were part of the environment for years prior to each birth and throughout

Table 1. Demographic information and amount of focal hours (HR:MM:SS) for each calf ($n = 4$) during each 10-d period ($n = 3$), delineated by on and off feeding session recordings

Calf	Sire/ dam	Sex	Date of birth (d/mo/y)	Time frame (d)						Total focal hours
				Days 1-10		Days 11-20		Days 21-30		
				Total data on session	Total data off session	Total data on session	Total data off session	Total data on session	Total data off session	
Baby Bit	Little Bit/ Dinghy	F	13/9/11	01:11:33	04:04:59	03:11:53	02:52:24	02:12:29	01:56:38	15:29:56
Isaac	Kimbit/ Samantha	M	1/6/11	03:45:55	01:35:11	00:18:55	00:28:34	02:46:33	00:50:06	09:45:14
Tashi	Bob/ Squirt	M	13/8/12	03:18:00	04:09:47	02:20:45	01:08:57	02:38:35	01:13:19	14:49:23
Zoe	Bob/ Jessica	F	14/7/10	04:59:33	04:42:54	03:54:01	01:14:33	00:54:29	00:52:02	16:37:32
				13:15:01	14:32:51	09:45:34	05:44:28	08:32:06	04:52:05	
Total per 10-d period				27:47:52		15:30:02		13:24:11		

Note: “On session” refers to feeding/training sessions for mothers, and “off session” (off-feed) periods are when animals are freely swimming, not under stimulus control, without food present.

the duration of the study. Thus, habituation was observed with the population through repeated exposure to the cameras prior to the study, and exploratory behavior to the stimulus (cameras) was not overtly evident in the data (Leussis & Bolivar, 2006). Dolphin whistles typically range from 5.0 to 20.0 kHz (e.g., Au et al., 1998), but frequencies can range higher, up to at least 30 kHz (e.g., Esch et al., 2009; Sayigh & Janik, 2010; Janik & Sayigh, 2013). Due to audio specifications for the cameras used, the current investigation was limited to only analyzing whistles or whistle-squawks between 0 and 22 kHz as these vocalizations, or components of them, exceeding 22 kHz would not be reliably recorded. For the current study, the fundamental frequencies of all of the recorded whistles produced by the focal calves did not exceed a maximum frequency of 20.64 kHz.

Procedures

Given the difficulty of determining the origin of a sound source when underwater without localization, especially as calves stay in close proximity to their mothers as neonates, we describe only whistles with concurrent bubblestreams. Limiting our sample to whistles with perfectly corresponded bubblestreams allowed us to conclude that the vocalization was produced by the calf. A similar methodological approach of analyzing calf vocalizations with concurrent bubblestream

was previously applied successfully (McCowan & Reiss, 1995; Herzing, 1996; Killebrew et al., 2001; Morisaka et al., 2005a, 2005b), and it was noted that the quality of the vocalization seemed unaffected by the bubblestream emission (Killebrew et al., 2001). The bubblestream-associated whistles in the current analysis likely only represent a subset of each calf’s vocal repertoire (Fripp et al., 2005).

Recording sessions ($N = 194$) occurred between the hours of 0800 to 1700 h during both feeding sessions (adult dolphins under stimulus control *sans* calf) and during off-feed periods (all animals freely swimming without food present; see Table 1 for total focal hours for each calf and 10-d subset). Whistle rates per hour and fine-scale analysis of three 10-d subsets (Days 1 to 10, 11 to 20, and 21 to 30) allowed for examination of parameter changes across the first month post parturition. Six parameters were assessed: duration, defined as the time between the beginning and end points of the vocalization; beginning and end frequency, operationalized as the frequency (kHz) of the beginning and end point, respectively, of the whistle or whistle-squawk contour; minimum and maximum frequency (kHz) of the lowest and highest frequency of the vocalization; and frequency range calculated by the minimum frequency (kHz) subtracted from the maximum frequency (kHz) (for review, see Morisaka et al., 2005a).

Analyses

Whistles were operationally defined as a continuous contour pattern on a spectrogram, unbroken by a period of time greater than 0.25 s (Sayigh et al., 2007). Whistle-squawks were defined as a frequency-modulated tone with the addition of broadband (appearing as blurred or chaotic on the spectrogram) characteristics (see Killebrew et al., 2001, for examples; Figure 1). Furthermore, all bubblestream whistles and whistle-squawks included did not have any overlapping vocalizations. If there were breaks in a contour of less than 0.25 s, it was considered one whistle emission with multiple loops (repeated elements) (Bazúa-Durán & Au, 2002; Fripp et al., 2005; Sayigh et al., 2007; Esch et al., 2009). Inclusion for fine-scale analyses required a calf to produce at least 10 bubblestream-associated whistle-type vocalizations recorded in their first 30 d. Thus, calf “Zoe” ($n = 4$) was omitted from subsequent inferential analyses. *RavenPro*, Version 1.4 (www.birds.cornell.edu/raven) was used to produce spectrograms for all vocalizations. Raven spectrogram parameters were consistently set as a Hann window (512 DFT), with a 50% overlap, a 256 hop size, and a 3-dB filter bandwidth. All vocal parameter measures were made manually and captured in *RavenPro* using the manual selection tool and selection table parameters.

Multivariate general linear mixed models (GLMM) and Chi-square goodness of fit tests provided a distribution analysis and parameter analyses of whistle and whistle-type vocalizations focusing on duration, beginning frequency, end frequency, minimum frequency, maximum frequency, and frequency range. Certain parameters (e.g., beginning or end frequency) of whistle-squawk vocalizations occasionally lacked observable detail (e.g., blurred portion on a spectrogram); therefore, analysis was delimited to bubblestream vocalizations with observable details to clearly identifiable parameters for all relevant sounds. All statistical analyses were conducted in *SPSS*, Version 24.

Interobserver reliability for vocalization classification (i.e., whistles, whistle-squawks) were conducted on a randomly chosen 20% of videos by a second blind coder: inter-observer reliability was confirmed at Pearson correlation coefficient: $r > 0.80$.

Spectrograms of five bubblestream-associated whistle examples, including the first and final whistle emission for each calf, across the 30 d were qualitatively assessed for differences in contour and quality. Bubblestream whistles produced in the first 30 d were subsequently cross-compared to signature whistles acquired from each subject through isolation events post age 2—“Baby Bit,” age 4; “Isaac,” age 3; and “Tashi,” age 3—to assess if

contours produced during the first 30 d resembled their signature whistles. Signature whistles of each dolphin were defined as the most frequently emitted whistle contour during out-of-water transports and medical procedures (Caldwell & Caldwell, 1965), and older than 2 y of age was methodologically chosen due to signature whistles becoming more stable during the second year of life (e.g., McCowan & Reiss, 1997).

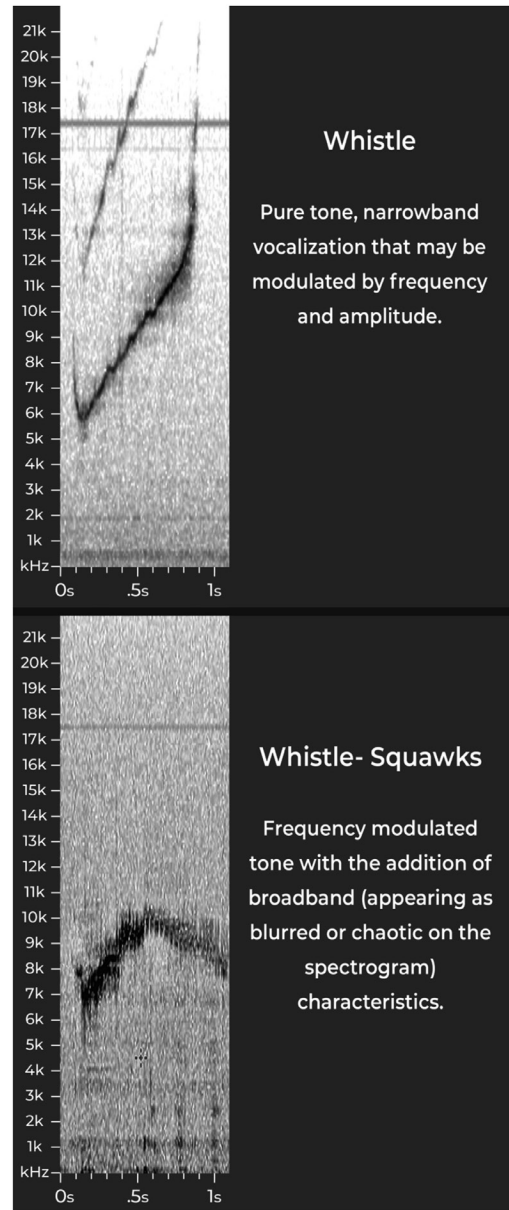


Figure 1. Operational definitions used to classify whistles from whistle-squawks using spectrogram analyses

Results

From 3,402 min of recorded video data spanning 194 recording sessions (see Table 1), 1,010 bubblestreams were observed from four calves; 791 (78.31%) of these were accompanied by a whistle or whistle-squawk for all calves combined ($N_{BB} = 532$, $N_{Isaac} = 71$, $N_{Tashi} = 184$, $N_{Zoe} = 4$; Table 2). Calf whistle frequencies ranged from 0.47 to 20.64 kHz, with durations from 0.05 to 1.35 s and 0 to 13 inflection points (Table 3).

Bubblestream-associated whistle rates per hour for the three focal calves with more than 10 bubblestreams were significantly greater in the third 10-d period (Days 21 to 30) compared to the first and second 10-d periods (Chi-square goodness of fit: $\chi^2(2, N = 620) = 877.3$, $p < 0.05$; Figure 2). During all three 10-d periods, all three calves consistently produced more whistle-squawks than narrowband whistles (Chi-square test of independence: $\chi^2(1, N = 620) = 102.43$, $p < 0.05$; Figure 3).

Individual Differences

To assess individual differences in the parameter changes over time, a GLMM with individual as a random subject variable was assessed and revealed a significant main effect of time period (Wilks' λ

$= 0.73$, $F(10, 1124) = 19.58$, $p = 0.00$, partial eta squared = 0.15); the significant random factor was individual (Wilks' $\lambda = 0.59$, $F(5, 562) = 77.28$, $p = 0.00$, partial eta squared = 0.41). Post hoc analyses revealed that when the intercept for each individual was included in the model, end frequency ($F(2, 566) = 73.76$; $p = 0.00$), maximum frequency ($F(2, 566) = 88.25$; $p = 0.00$), minimum frequency ($F(2, 566) = 5.97$; $p = 0.00$), frequency range ($F(2, 566) = 33.89$; $p = 0.00$), and duration ($F(2, 566) = 9.35$; $p = 0.00$) all significantly changed across the three 10-d periods. Significant individual differences were found for the beginning frequency ($F(1, 566) = 6.28$; $p = 0.01$), end frequency ($F(1, 566) = 240.673$; $p = 0.00$), minimum frequency ($F(1, 566) = 9.62$; $p = 0.02$), and duration ($F(1, 566) = 12.75$; $p = 0.00$).

Pairwise comparisons further revealed that end frequency, maximum frequency, and frequency range were all significantly higher in the third 10-d period (end frequency: $M = 12.01$, $SE = 0.15$; maximum frequency: $M = 13.86$, $SE = 0.11$; frequency range: $M = 7.28$, $SE = 0.13$) compared to the first 10-d period (end frequency: $M = 5.49$, $SE = 0.79$; maximum frequency: $M = 8.35$, $SE = 0.57$; frequency range: $M = 3.10$, $SE = 0.71$; $p = 0.00$, $p = 0.00$, $p = 0.00$, respectively) and the

Table 2. Total number of bubblestream and whistle-type vocalizations produced with bubblestreams and percentages of vocalization on bubblestream for each calf ($n = 4$) during their first 30 d postpartum

Calf	Total number of bubblestreams	Total number of bubblestream vocalizations	Whistle vocalizations with bubblestream	Whistle-squawk vocalizations with bubblestream
Baby Bit	622	532 (85.53%)	146 (27.42%)	386 (72.58%)
Isaac	87	71 (81.61%)	56 (79.50%)	15 (20.50%)
Tashi	255	184 (72.16%)	140 (76.33%)	44 (23.66%)
Zoe	46	4 (8.69%)	2 (50.00%)	2 (50.00%)
Total	1,010	791 (78.31%)	344 (34.03%)	447 (44.25%)

Table 3. Whistle-type vocalization parameters for all calf emissions produced with bubblestreams

Whistle parameter	Minimum	Maximum	Mean	Std deviation
Beginning frequency (kHz)	0.62	19.17	7.47	2.64
End frequency (kHz)	0.73	20.27	11.46	4.05
Maximum frequency (kHz)	1.10	20.64	13.34	2.80
Minimum frequency (kHz)	0.47	13.78	6.51	2.20
Frequency range (kHz)	0.41	17.59	6.83	3.15
Duration (s)	0.05	1.35	0.47	0.22

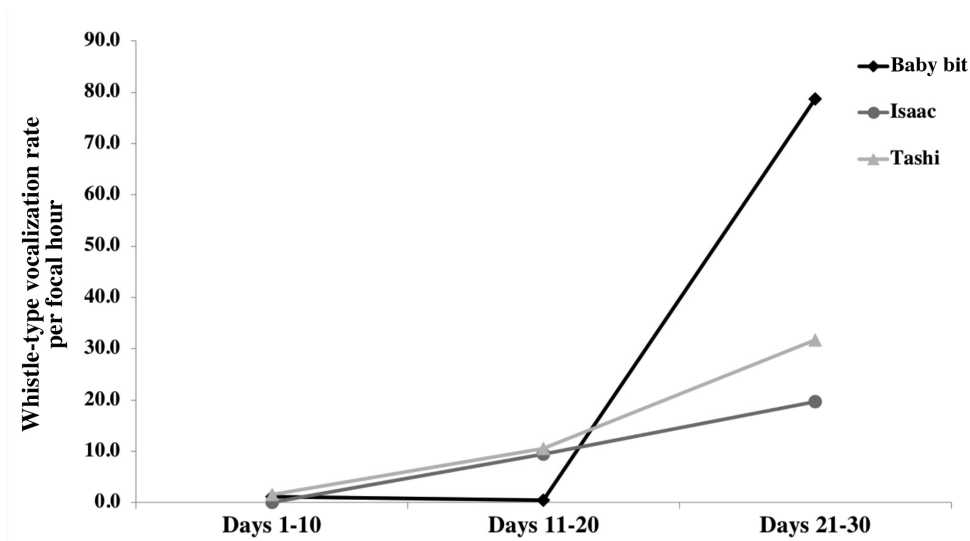


Figure 2. Bubblestream-associated whistle rates per focal hour for each calf over the three 10-d sampling periods

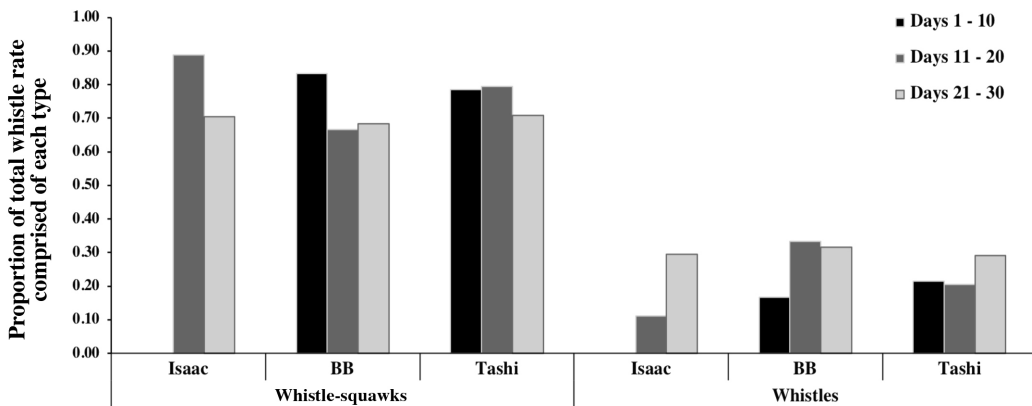


Figure 3. The proportion of whistle-type vocalizations categorized as whistles and whistle-squawks produced by each calf over the three 10-day sampling periods

second 10-d period (end frequency: $M = 5.83$, $SE = 0.61$; maximum frequency: $M = 9.20$, $SE = 0.44$; frequency range: $M = 3.69$, $SE = 0.54$; $p = 0.00$, $p = 0.00$, respectively) of life. The duration of the whistles also significantly increased from the first ($M = 0.29$; $SE = 0.05$) to the third ($M = 0.48$; $SE = 0.01$) 10-d period ($p = 0.00$).

Five bubblestream-associated whistle examples from each calf, including the first and final recorded whistle emission, are depicted in Figure 5. Initial whistle production for calves varied as Baby Bit's first recorded emission was on Day 2, Tashi's was on Day 3, and Isaac's was on Day 13. Individual differences in whistle contour and quality were

apparent, with Isaac the only calf to produce a stereotyped, repeated whistle contour during his first 30 d. Baby Bit also repeated the same contour three times, but they lacked consistency among and between emissions. Subsequent analyses of each calf's signature whistle during isolation events after 2 y of age—Baby Bit, age 4; Isaac, age 3; and Tashi, age 3—found that none of the three focal dolphins produced a whistle contour that largely resembled their signature whistle during their first 30 d (Figure 6). Although Isaac repeatedly produced a stereotyped whistle contour after Day 27, this contour lacked the fundamental qualities of his signature whistle.

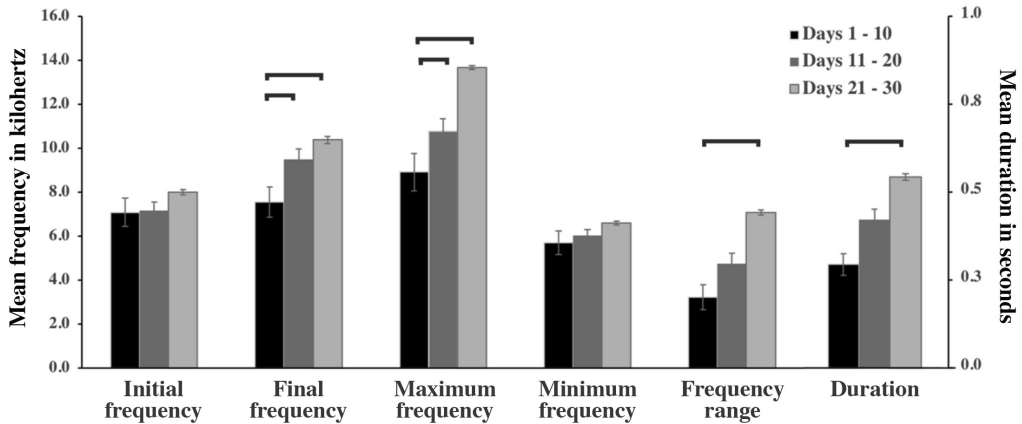


Figure 4. Whistle parameter changes over time, with overall means (± 1 standard error) of calf whistle parameters for each 10 d period of the first 30 d of life when all three calves are combined. Brackets represent significant differences between the two time periods for that variable when individual differences are accounted for (i.e., reported by the GLMM; individual dolphin included as a random subject variable).

Discussion

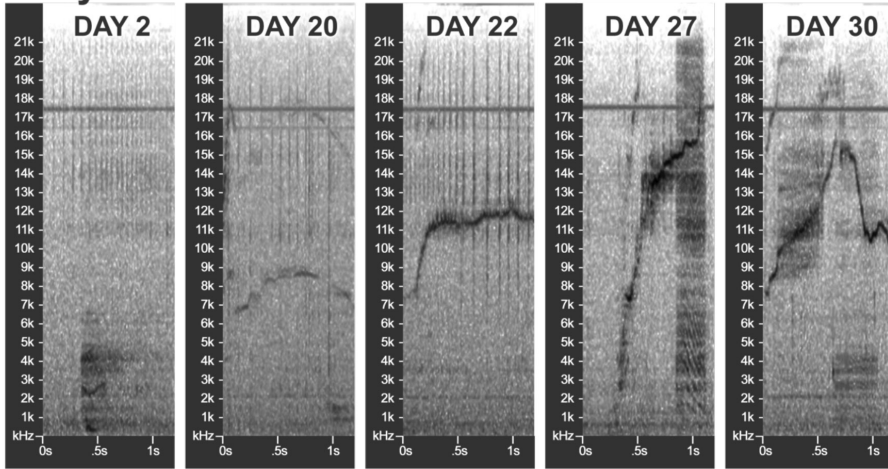
Four Atlantic bottlenose dolphin calves were observed producing whistle-type vocalizations in the first month of their lives; of the bubblestreams emitted, over three-quarters were accompanied by a whistle-type vocalization. Though rare, two focal calves (Baby Bit and Tashi) produced clear, precise whistles with concurrent bubblestreams during the first 5 d of life. Whistle-squawks were observed more frequently than whistles throughout the first 30 d postpartum, with distinct narrowband whistles generally increasing from an average of 20 to 30% of whistle production during this developmental period for these calves. These results may be a result of physical maturation, improved muscle control, prolonged respiration duration, or greater neuronal activation patterns given that older calves have the ability to produce clear, unbroken narrowband whistles (e.g., Caldwell & Caldwell, 1979; McCowan & Reiss, 1995; Killebrew et al., 2001; Morisaka et al., 2005a).

The calves in this study did not seem to develop signature whistles associated with bubblestreams during their first month of life, results that are consistent with Caldwell & Caldwell (1979), Sayigh (1992), and Gnone et al. (2001). While clear narrowband whistle contours were present by the end of the first 30 d for the three calves in this study, the majority of their whistles (> 50%) continually possessed the blurred broadband quality characteristic of whistle-squawks. Similar to McCowan & Reiss (1995), the calves in this study varied in the amount and types of vocalizations they produced.

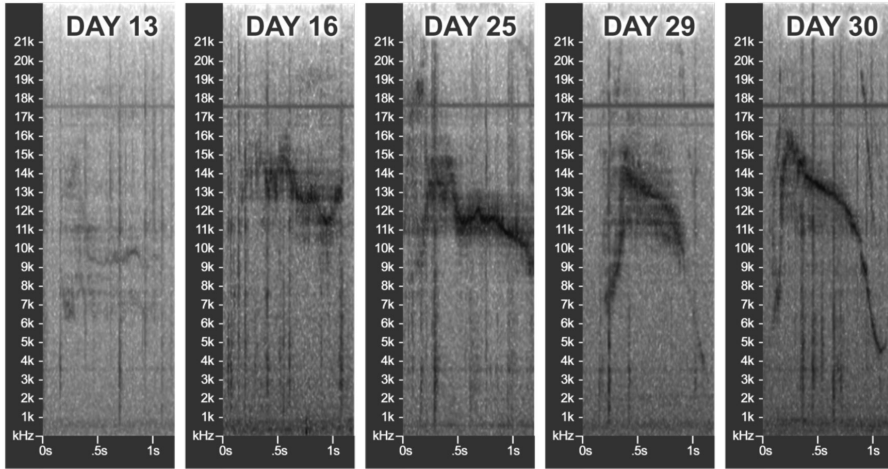
The parameter results supported the hypothesis that vocal production systems develop over the first 30 d of life as calves produced longer duration whistles covering a broader frequency range. Similarly, Caldwell & Caldwell (1979) reported a “slight” increase in the frequency range of whistles by dolphin calves as they aged. Maximum frequency exhibited the greatest change over the first 30 d, with relatively significant differences among all three time periods. Calves’ ability to produce higher frequencies appears to improve as they mature. One potential explanation is that as a calf becomes adept at producing whistles in a particular range. It is possible that bubblestream emission may be associated with more “difficult” emissions at the limits of the calf’s ability and that the whistles in the range that the calf is comfortable producing are no longer produced with a concurrent bubblestream. Even if this were the case, it would suggest that calves improve their ability to control their vocal range over time. Additional studies are necessary to identify if it is a result of physiological maturation, the impact of the acoustic environment of the calf, and/or the transition to producing certain whistle types without a congruent bubblestream that resulted in this increased maximum frequency, range, and duration of calf whistles over time.

In the current study, Isaac’s onset of whistle production was later than the other three calves (Day 13), but Isaac had the earliest emission of a repeated whistle contour shape (Day 27). From Day 28, Baby Bit was recorded repeating the same contour three times consecutively, but these contours were neither consistent across the three bouts

Baby Bit



Isaac



Tashi

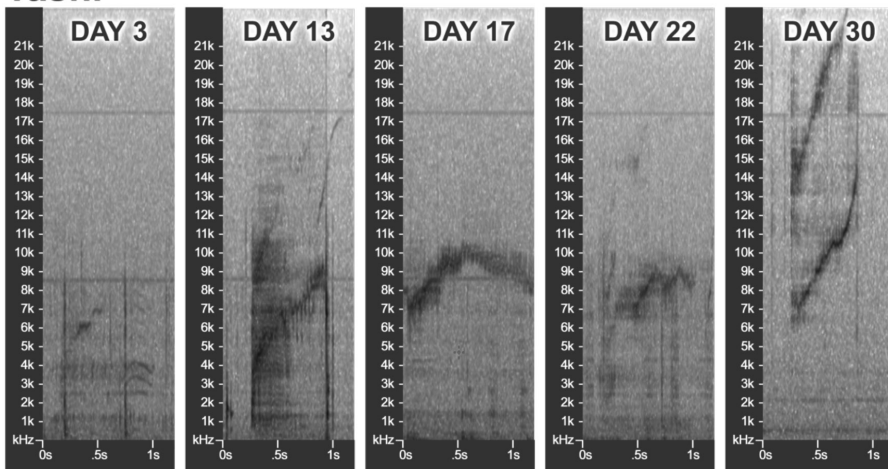


Figure 5. Spectrogram examples (frequency [kHz] on the y-axis and time [s] on the x-axis) of Baby Bit, Isaac, and Tashi's whistle progression, including the first and last emission during the first 30 d of life

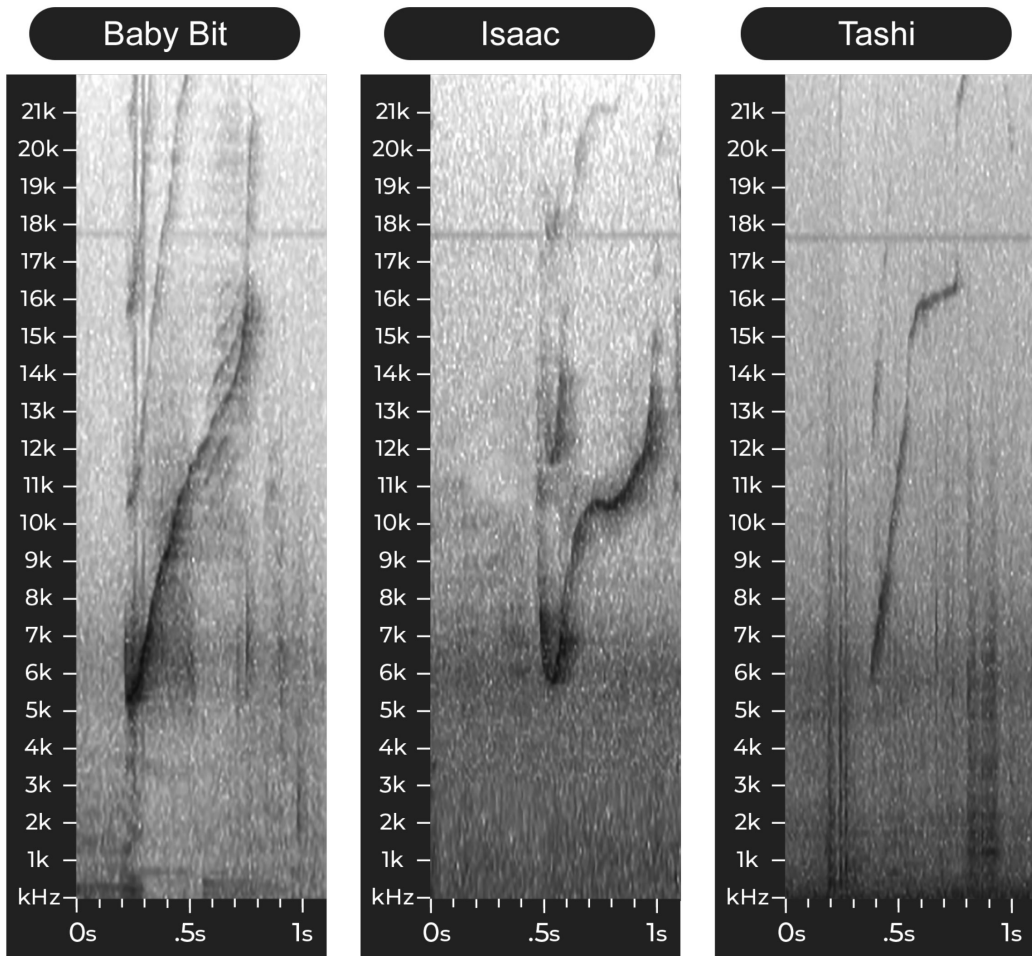


Figure 6. Spectrograms of signature whistles for Baby Bit, Isaac, and Tashi (frequency [kHz] on the y-axis and time [s] on the x-axis) acquired through isolation (Baby Bit, age 4; Isaac, age 3; and Tashi, age 3)

of repetition nor in subsequent recordings. Tashi did not produce repeated contours during the 30-d study period. None of the recorded repetitive contours were representative of their crystallized signature whistles later in life. A consensus in the literature suggests vocalizations among calves lack defined frequency-modulated contours; however, they are acquired as the calves develop (Caldwell & Caldwell, 1965, 1979; Caldwell et al., 1990; Sayigh, 1992; McCowan & Reiss, 1997). These results suggest that the ability to repeat a whistle contour shape multiple times in a bout is a stage of whistle development that seems to precede the acquisition of a signature whistle contour. That said, repeated emissions of a frequency contour pattern only started toward the end of the 30 d, suggesting that the ability to produce clear narrow-band whistles and the ability to produce a repeated

or even stereotyped whistle contour may develop independently. Further investigations focusing on the specifics of vocal development among dolphins may give insight into the ontogenetic system (Caldwell & Caldwell, 1979; Killebrew et al., 2001).

Bottlenose dolphin neonates practice whistling by overproducing several different whistle segments before they are able to produce adult-like whistles (e.g., Tyack & Sayigh, 1997). During spectrogram analysis, three focal calves in this study repeatedly used different whistle segments as early as Day 5 and continued to do so throughout the entire sampling period. Whistles among the calves exhibited various temporal patterns. These bouts of constant vocalizing are often a mix of burst pulses, whistle-squawks, and whistles; possess many different qualities and contours;

and are potentially developmentally necessary to produce stable whistles (Morisaka et al., 2005a).

Unfortunately, this study was limited by a small sample size of three calves. Further, we describe the whistle development of vocalizations with concurrent bubblestreams but are unable to compare this to those emitted without bubblestream in this focal group. Finally, it would be useful to follow calves from birth to the full development of their signature whistle to get a more complete picture of the process of whistle development in dolphin calves.

Conclusions

This study provides supplementary evidence that neonate calves produce whistle and whistle-squawk emissions concurrent with bubblestreams—as early as their first few days of life. The majority of whistles recorded during the first 30 d of life were characterized by a screechy, unclear quality, which appears as a broader-band, chaotic, or blurred component on a spectrogram and is related to the properties of whistle-squawks. Whistle rate, maximum frequency, frequency range, and duration were all positively correlated with calf age during this neonate stage, suggesting that as the vocal apparatus and respiratory system mature, calves are able to reach higher frequencies and emit longer, clearer whistles. While there are likely apparent growth-related trends, there were also individual differences in whistle development between these three neonate calves. These data provide additional information on whistle parameter changes for vocalizations with concurrent bubblestreams for the first 30 d postpartum. Future research should include analysis of whistles that do not co-occur with bubblestreams to better understand whether the bubblestream emission is an identifying cue for the vocalizer and for quantitative and qualitative differences between vocalizations produced with and without them. Finally, extending this study to include more dolphins and a longer time frame to include the full crystallization of the signature whistle is needed.

Acknowledgments

Gratitude is extended to the staffs of Dolphins Plus, Dolphins Plus Marine Mammal Responder, and Island Dolphin Care for allowing us access to their dolphin populations, as well as for Dr. Stan Kuczaj's collaboration with the project. Additionally, thank you to the Dolphins Plus research interns and the graduate students of the Marine Mammal Behavior and Cognition Laboratory at the University of Southern Mississippi, specifically Kelley Winship and Christina Perazio. IACUC approval for this study was gained from the University of Southern Mississippi.

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