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Modern applications of operant conditioning through the training of a beaching behaviour with bottlenose dolphins *Tursiops truncatus*

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Abstract

Operant conditioning techniques, such as positive reinforcement and shaping through successive approximation, are used in applied settings to train a variety of species to complete behaviours voluntarily. The reinforcement and shaping procedures implemented by trainers can vary widely and are generally guided by qualitative assessment rather than quantitative data. The aim of this study was to complete a preliminary investigation of several factors that may affect the success of training a new behaviour in order to present information on current techniques and determine focus areas for future studies employing experimental designs. Data were collected during training sessions involving six bottlenose dolphins *Tursiops truncatus* at the US Navy Marine Mammal Program in San Diego, CA. The focal behaviour required the dolphin to slide up and out of the water and beach onto a foam transport mat. The study discusses three components of operant conditioning: 1) How often should a behaviour be shaped? 2) When and how often should the behaviour be reinforced? 3) How are criteria changes or previous beaches related to future success? Based on these data, limiting the number of distance building approximations within a session may play a role in acquisition. Providing small reinforcement magnitudes for attempting did not clearly promote successful beaches but also did not seem to hinder success. The duration of hand station avoidance was related to the outcome of the previous trial but did not impact the following trial.

Introduction

Shaping is a training method in which successive approximations of a target behaviour are reinforced until the desired topography is exhibited (Skinner 1953). In a shaping procedure, behavioural responses that meet a predetermined criterion are reinforced. The criterion for reinforcement is then adjusted until the responses match the target behaviour. The shaping model is used to train a wide range of species, including everything from monkeys (Gillis et al. 2012) to sharks (Marranzino 2013). It is effective for training complex behaviours for biomedical and cognitive research (Reinhardt 2003; Schapiro et al. 2003; Scott et al. 2003; Veeder et al. 2009).

Although the techniques for implementing shaping procedures are generally qualitative in nature and vary among trainers (Galbicka 1994), the use of small, achievable successive approximations (i.e., steps) are widely considered to be effective in animal training (Gullapalli and Barto 1992). Small step sizes increase the probability that the criterion will be met after each step change (Galbicka 1994) and have been shown to be optimal for shaping behaviours along multiple dimensions (Lane et al. 1967). Relatively larger step sizes are ideal during acquisition rates for behaviours with a single dimension. For example, large shaping steps optimised performance while training pigeons to peck at specific time intervals (Alleman and Platt 1973; Kuch and Platt 1976) or locations (Eckerman et al. 1980).

In addition to step size, reinforcement magnitude affects rate of skill acquisition (Hutt 1954; Reed 1991). In contemporary dolphin training, both unconditioned and conditioned

Table 1. Subject demographic information.

Dolphin	Age (years)	Gender
D1	3	Male
D2	2	Male
D3	2	Male
D4	5	Male
D5	6	Female

Figure 1. A: Dolphin responds to the hand station S^D that precedes the beach S^D. B: Dolphin beaches onto the transport mat.

reinforcers are regularly provided in response to a successful approximation. Unconditioned reinforcers are inherently rewarding, such as fish, because they satisfy a biological drive (Pryor 2009). Conditioned reinforcers are stimuli that have gained their reinforcing value through their repeated association with unconditioned reinforcers. For example, the bridging stimulus, ice, enrichment devices, tactile contact and water play are conditioned reinforcers commonly used in training sessions. Reinforcement magnitude refers to the amount or duration of the provided reinforcer for the response (Hoch et al. 2002). The magnitude of unconditioned reinforcement can be increased by increasing the number of fish or by providing highly preferred species. Conditioned reinforcers are also used in combination with unconditioned reinforcement. Although reinforcement schedules for marine mammal training are addressed in prominent animal training manuals (Rameriz 1999), no guidelines are reported for determining the exact magnitude of unconditioned reinforcement to deliver for successfully completing new approximations for an individual. The rate of reinforcement, or the schedule, refers to the rules that govern how often reinforcement is delivered. Marine mammal training employs a continuous schedule of reinforcement with the bridge (a conditioned reinforcer) being used to mark the most successful behaviour and followed by primary and other secondary reinforcers on either a continuous or variable schedule. Unconditioned and conditioned reinforcement is provided on a variety of schedules based on the behaviour and training goals.

The aim of the present study was to discuss: 1) how often a new behaviour should be shaped; 2) how criteria changes and previous outcomes are related to future success and; 3) how much and when a behaviour should be reinforced. Beaching is a trained behaviour used to transfer dolphins from the water to a cushioned transport mat onboard a boat or dock. For the purpose of this study, beaching was partitioned into specific criteria providing a clear distinction between success and failure (i.e., attempt or no attempt), had a quantifiable step size, and was regularly practiced allowing for consistent training and observation opportunities. These qualities provided a unique opportunity to explore potential relationships between the frequency of training sessions, quantity of approximations, criteria change and reinforcement.

Materials and methods

The subjects were five bottlenose dolphins *Tursiops truncatus* (Table 1). They were housed in floating, netted enclosures at the US Navy Marine Mammal Program in San Diego Bay, California. The dolphins lived in a series of connecting 9×9 m and 9×18 m enclosures, which exposed them to natural tides and temperature changes, as well as native flora, fauna and human activities common in the bay. The subjects were selected because they regularly participated in beaching sessions with criterion requiring no less than one third of their body on the mat. Subjects began learning the initial approximations of the beaching behaviour as calves, and as a result the length of prior experience varied for each subject.

In order to transport dolphins, the US Navy Marine Mammal Program trained dolphins to slide up and out of the water and beach onto a foam transport mat. The training requirements for initial stages of beaching included establishing a hand station in front of the transport mat, beaching straight onto the mat, occasionally eating fish, and returning to the water while maintaining the hand station. Beaching was shaped using small approximations that slowly increased the distance from the edge of the mat to the trainer's hand. To perform this behaviour, the subject was presented with the hand station discriminative stimulus (S^D) followed by the beach S^D (Figure 1), in which the trainer moved backwards on the mat and repositioned their hand to indicate the distance criterion the dolphin was required to beach. The trainer's hand remained at this distance until the subject touched it with their rostrum. A successful beach was completed when the dolphin beached onto the mat and successfully touched the trainer's hand with their rostrum at the desired position on the mat. The trainer then helped the dolphin to slide back into the water, re-established hand station, and bridged the behaviour.

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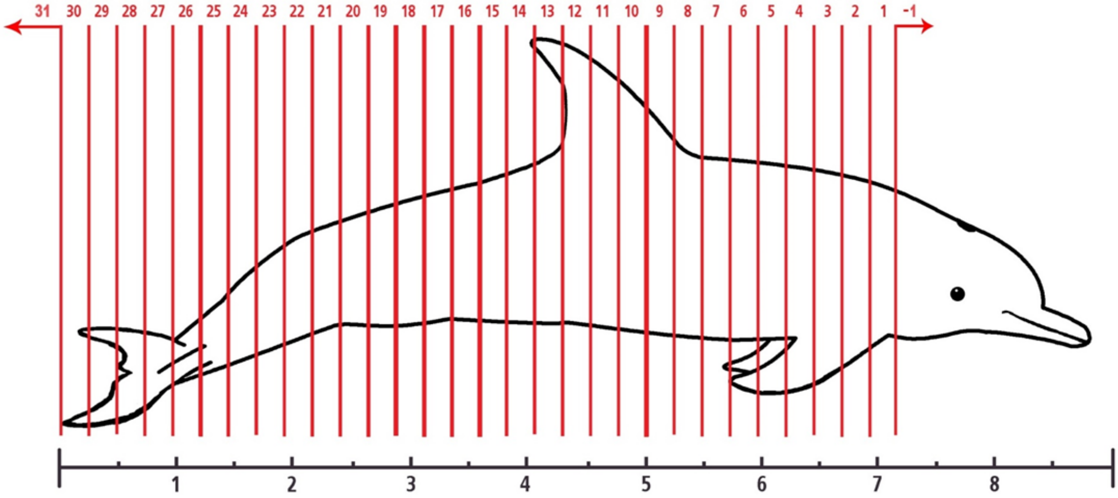

Figure 2. The location of each distance criterion in relation to the dolphin's body.

The distance each dolphin was required to beach varied between trials and the farthest requested distance in each session increased as the dolphin became proficient at shorter distances. Trainers often toggled back and forth between increasing the duration of time the dolphin spent on the mat at a shorter distance and a quick in-and-out beach at a longer distance (i.e., the trainers were working on multiple beaching criteria with the length of the beach distinguishing which behaviour was requested behaviour). A successful beach was bridged when the dolphin met the distance and/or duration criteria. When unconditioned reinforcement (e.g., capelin and herring) was provided for beaching, it was generally delivered immediately upon re-entry to the water from the beaching mat; however, reinforcement was also delivered on some trials during the short period of time while the dolphin was on the beaching mat. While increasing distance beached on the mat was the primary focus of the training sessions presented in the present study, trainers were simultaneously sustaining other criteria such as beaching straight (as opposed to crooked) into the mat, maintaining the hand station upon re-entry, and preserving a relaxed body posture.

The outcome for each beaching trial was coded as 'success', 'attempt', or 'no-attempt'. Trials were considered a success when the dolphin met the predetermined distance criterion by touching the trainer's hand with their rostrum after the beach S^D was presented and remained on the mat until pushed backward by the trainer (i.e., the trainer added pressure with their hand to the dolphin's rostrum to indicate to the dolphin to propel itself backwards). Attempt trials and no-attempt trials were considered failures but were distinguished by the degree of effort exerted by the dolphin. Trials were considered an attempt when more than one third of the dolphin's body left the water with a forward trajectory but the animal did not meet the distance criterion after the presentation of the beach S^D. Trials were considered a no-attempt when less than one third of the dolphin's body left the water after the presentation of the S^D. Duration of avoidance was coded when the dolphin did not complete the hand station behaviour in response to the hand station S^D that preceded the beach S^D.

Beaching sessions were recorded using a Canon Powershot S110 video camera from May 2014 to August 2014. Each trainer determined step size, as a function of distance and distance beached. The timing, type (e.g., species) and magnitude of reinforcement was likewise determined by the trainer. Video data of sessions were coded for the magnitude and species of reinforcement fed while in the mat and after the completion of the behaviour in the water. Dolphins were fed capelin, herring, squid and mackerel during sessions. Reinforcement for beaching trials was coded to include the species of fish fed and the approximate amount in whole and half fish increments. The distance criterion and distance beached were identified to determine shaping step size. The distance criterion range analysed varied for each dolphin observed during the collection period. The distance criterion was coded as the distance the trainer requested the dolphin to beach. The distance beached was coded with respect to how much of the subject's body was beached on the mat. To standardise across individuals of different sizes, the dolphin's body length was divided into 32 numbered units (Figure 2). That is, units were based on body ratio rather than numeric distances. Therefore, the number

Table 2. Session information and mean success rates.

Dolphin	D1	D2	D3	D4	D5
Number of sessions	26	24	33	25	30
Number of trials	91	101	158	214	266
Average trials per session	3.50	4.21	4.79	8.56	8.87
Average hours between sessions	48.05	67.77	63.25	50.58	55.34
Mean rate of success (%)	75.82	69.31	90.51	71.50	33.83
Mean rate of attempt (%)	24.18	27.72	8.86	28.38	59.77
Mean rate of no-attempts (%)	0.00	2.97	0.63	0.00	6.39
Cumulative distance gained	56	28	19	17	7
Average criteria change between trials	1.23	1.02	0.26	0.77	0.50

of distance units the criterion increased determined the step size. Inter-observer agreement was achieved across subjects using 20% of the video data with both coders reaching at least 80% reliability (Haidet et al. 2009).

Only sessions in which the trainer was either maintaining the farthest two shaping step sizes or increasing the farthest distance beached were included in the analysis. The total distance gained was used as a proxy for the overall success in training the behaviour. Rates of successes and attempts were calculated by dividing the number of successful trials by the total number of trials. Inferential statistics for between subjects relationships were not calculated due to the small sample size. Avoidance was calculated as the time between the hand station S^D and completing the behaviour for durations longer than 5 s.

Generalised estimating equations (GEEs) were used to analyse data. GEEs are an ideal tool for data that are correlated or not normally distributed and allow for analysis of data with repeated measurements (Zeger et al. 1988; Feng et al. 2014). GEEs were conducted to examine the significance of relationships between avoidance and the current trial outcome, previous trial outcome, and trial number within the session. In addition, a GEE was calculated to assess the relationship between avoidance and reinforcing dolphins on the beaching mat. Finally, the relationship between the change in criteria between trials and the outcome was examined using GEE.

Results

Dolphins completed between 24 and 33 sessions focussed on increasing the distance they beached. On average, sessions were 57 hr apart (SD=8.35, range=48.05–67.77 hr). Trainers requested the dolphins to beach an average of 5.98 times per session (SD=2.53, range=3.50–8.87). The mean rate of success for beaching trials was 68.10% (SD=20.91, range=33.83%–90.51%; Table 2). The mean rate of attempts was 29.78% (SD=18.54, range=8.86%–59.77%) and mean no attempt rate was 2.00% (SD=2.74, range=0.00%–6.39%).

While the sample size was too small to conduct inferential

Table 3. Maximum and average species and magnitude of reinforcement on successful trials.

Dolphin	Average capelin	Max. capelin	Average herring	Max. herring	Average caplin on current farthest beach	Average herring on current farthest beach	% of trials reinforced on the mat
D1	3.59	22	7.27	40	5.30	10.88	49.45
D2	1.82	9	2.98	7	2.53	3.79	3.96
D3	0.68	11	2.15	10	1.11	2.99	1.90
D4	4.72	30	2.97	14	8.32	6.24	24.30
D5	4.39	24	4.55	28	8.00	9.40	0.00

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Table 4. Maximum and average species and magnitude of reinforcement on attempt trials.

Dolphin	Average capelin	Max. capelin	Average herring	Max. herring
D1	0.07	1.0	0.14	1.5
D2	0.05	3.0	0.39	3.5
D3	0.07	1.0	0.29	3.0
D4	0.20	2.0	0.03	0.5
D5	0.16	2.0	0.03	1.0

statistics on between subject features of training, several potential relationships have been identified as starting points for future studies. An apparent inverse relationship existed between total number of trials and the distance gained throughout the study. Dolphins that completed more trials gained less distance when compared to their peers. No immediate relationships were discernible between the intersession interval or the number of sessions and the cumulative distance gained.

Results of the GEE model indicated that there were not significant differences in duration of avoidance between a successful or failed outcome on the following trial (df=1, β=-1.198, P=0.185). Avoidance was significantly higher on a trial following a failed outcome than a successful one (df=1, β=-4.223, P<0.001). The GEE model testing the trial number within the session and duration of avoidance was not significant (df=1, β=0.167, P=0.063). The change in criteria did not significantly predict the outcome of the trial (df=1, β=-0.296, P=0.13). Finally, reinforcing trials on the beaching mat was not significantly related to avoidance (df=1, β=0.6292, P=0.706).

Unconditioned reinforcement for trials included capelin, herring, squid and mackerel in the water and capelin and herring in the mat. Fish was delivered in varying magnitudes. Squid and mackerel made up 1.05% of the total fish reinforcers used and therefore were excluded from the analysis. Dolphins were reinforced on a continuous schedule with the magnitude of reinforcement increasing alongside the difficulty of the approximation. Average and maximum number of capelin and herring delivered after successful beaches are presented in Table 3. Dolphins always received fish reinforcement for successful trials and never received fish reinforcement following no attempt trials. Average and maximum number of capelin and herring delivered after attempted beaches are presented in Table 4. The maximum amount of food reinforcement each dolphin received for attempts never exceeded 50% of what they received for successful beaching, which in most cases was more than an order of magnitude larger.

Discussion

How often should a new behaviour be shaped?

Several investigators (e.g., Rubin et al. 1980; Meyer and Ladewig 2008; Demant et al. 2011) have suggested that the number of training sessions impact the rate at which a trained behaviour was acquired. For example, weekly training sessions for dogs and horses were more effective in completing shaping criteria than daily training sessions (Rubin et al. 1980; Meyer and Ladewig 2008). Similarly, Fernström et al. (2009) found no additional benefit in training rhesus macaques more than once a day.

The present study did not reveal any obvious relationship between the intersession interval for trials working on increasing distance and total distance gained. However, this is somewhat expected as the range of intersession intervals was relatively small between subjects and beaching sessions focussed on other aspects of the behaviour often occurred between beaching sessions focussed on increasing distance. Similarly, there was a relatively small range for the total number of sessions and there was no clear relationship to overall success in terms of distance gained.

Within the session, there may be an inverse relationship between the average number of trials per session and distance gained as dolphins with lower number of trials also gained some of the larger cumulative distances amongst the participants. However, it is also possible the trainers requested more trials due to a higher number of failed trials prior to a successful beach. As D3 and D4 had similar or higher levels of success than their counterparts who gained more distance, it is more possible that fewer beaches per session facilitated success. This may be due to frustration following the cumulative effects of failure; however, further research is necessary to ascertain a cause.

How are criteria changes and previous beaches related to future success?

There was no significant relationship between the criteria change and the outcome of the trial. However, the data suggested that larger shaping step sizes may be related to more total distance gained for four of the five participants. Previous studies have found conflicting results regarding optimal step size; therefore, it is important to clarify that the definition of a large or small step size is arbitrarily assigned based on the range of criteria in the study. For example, step sizes ranging between 0.5 and 3 in were used to train pigeons to peck a response area in specific pattern (Eckerman et al. 1980). Short distances (i.e., 0.5 in) were designated as small step sizes and far distances (i.e., 3 in) were large step sizes. Although Eckerman and colleagues (1980) found that larger step sizes optimised learning, but an even larger step size (e.g., 5 in or 7 in) may have resulted in a decrease in performance. Optimal ranges of step size likely differ based on the individual learning the behaviour, the behaviour of interest and other variables (e.g., reinforcement history, trainer preference, trainer ability and previous trials).

Dolphins were more likely to avoid the hand station if they had failed on the previous beach. Although dolphins were less likely to promptly commit to a hand station after failure, the duration of avoidance did not impact the result of the next trial. In addition, avoidance did not increase as subsequent trials were requested. Given that avoidance was related to the outcome of the previous trial and did not impact future trials, it is possible that the dolphins were resilient after failures, and that failures did not have a compounding effect on avoidance of the hand station.

How much and when should a behaviour be reinforced?

In the present study, dolphins were reinforced on a continuous schedule with variable magnitudes of reinforcement and the highest magnitudes of reinforcement were provided for the farthest successful approximations. This highlights the importance of developing training plans that include procedures for changing schedules of reinforcement magnitude. Further, training and reinforcement plans can be easily monitored by an observer periodically to ensure implementation.

Currently, no publications exist describing salient or high magnitudes of reinforcement or the magnitude increases used during training sessions with bottlenose dolphins. While this study did not aim to determine appropriate magnitude or increases, it is hoped that these data provide a starting point for others to gauge the magnitudes of reinforcement they currently deliver during successful training.

Dense reinforcement schedules are often considered to be optimal for learning (Koegel et al. 1988). In this study there was no obvious relationship between higher reinforcement rates of attempt trials, which resulted in a denser overall reinforcement schedule, and a higher proportion of attempt trials, and appeared to have little impact on the mean failure rate or the acquisition of a behaviour. It was possible that reinforcing attempts may have aided in increasing the likelihood of participation in the training session. Koegel et al. (1988) suggested that denser reinforcement rates motivated subjects to continue responding, which may lead to the production of more correct responses in the future.

In traditional operant conditioning, it is considered problematic to reinforce effort for attempting a behaviour that did not meet criteria (Ramirez 1999). This argument is founded in the idea that there is no way to explain to the animal that their effort is being reinforced and not the incorrect response. Instead, the trainer is communicating what the correct behaviour is (e.g., beaching short of the hand target rather than touching the hand target). In the present study, trainers worked to provide the dolphins with clear expectations of the criteria while occasionally providing small amounts of fish reinforcement following a solid re-entry from an attempted beach. Of behaviours typically trained to dolphins using shaping, beaching is unusual because the behaviour required to meet the new criteria as it is being shaped is very clear. The requirement for the dolphin to touch the trainer's hand is consistent and only the location of the hand is changed. Therefore, it is always clear to the dolphins, what the distance criteria is throughout the shaping process.

Though dolphins were reinforced for attempting the behaviour, there were notable differences that distinguished successful and unsuccessful beaches. Beginning with the conditioned reinforcer of feeling their rostrum touch the trainer's hand on successes, there were abundant cues that marked the difference to the dolphin. Further, unsuccessful beaches were not bridged upon re-entry to the water which communicates to the dolphin that they have not met the criterion. Successful trials were always followed by food reinforcement either in the mat, upon re-entry to the water, or both. On the rare occasions that dolphins received reinforcement after unsuccessful beaches, it was a much smaller magnitude (range: 0.5–3 fish) when compared to the amount of reinforcement received for successful beaches (range: 0.5–40 fish). The prominent differences allow trainers to maintain a clear distinction between success and failure while still effectively reinforcing participation. In addition, unsuccessful beaches were not bridged in order to avoid confusing the animal and associating the fish with remaining with the trainer. Feeding an attempt was not a grey area of judgement. Attempts were fed following their own criteria based on the number of previous failures and the performance on the prior beach.

When employed alongside abundant cues that the distance criterion was not met, the limited use of providing small amount of reinforcement after a failed attempt did not appear to be detrimental to the learning process nor confusing to the dolphin. Occasional minimal reinforcement after a failed approximation was used to reinforce the dolphin for continuing to participate in the session. Dolphins voluntarily participated in the sessions and received their diet regardless of participation.

Limitations

These results provide a foundation for future research in this area. Evaluations of applied training protocols possess several inherent confounds that must be addressed. Most notably, many training programmes are not uniform, are designed by individual trainers, and are based on their previous experiences with individual animals. Additionally, given the small sample size and individual differences in the results, the present study should be regarded as a pilot study to obtain basic information on the elements of failure while learning a challenging task in bottlenose dolphins. It is acknowledged that many factors, including the life history of the dolphin, previous experiences beaching, other training sessions occurring that day, trainers' experience level, training style and relationship with the dolphins, influenced their decisions to change criterion and select the magnitude of reinforcement. Furthermore, the animal's criteria and reinforcement history likely contributed to their training success and persistence.

Future research

As other research has found effects of the frequency of sessions, this study recommends a controlled study that varies intersession intervals. An experimental study manipulating the number of trials in a session may yield insight into how and if repetition impacts success. Based on these data, there may be an interaction between average criteria change and total distanced gained as four of the five participants aligned with a potential relationship. Success and attempt rates followed a similar pattern that may be related to total distance gained with the same four of the five participants. Given the possibility of these relationships, experimental studies should be conducted to clarify these tentative links to determine if a smaller number of larger steps may yield greater distance gained or increased success.

Future research should also focus on the implications of reinforcing after an attempt, specifically how this affects the dolphin's participation in the session. Additional investigation is needed to identify the function of the avoidance and its relationship to prior trial outcomes. Finally, the manner in which individual differences (e.g., personality and age) and situational factors (e.g., trainer or behaviour of interest) affect failure rates and persistence should also be examined.

Conclusion

Based on these preliminary data, more sessions were not helpful in improving distance beached. In addition, limiting the number of distance building approximations within a session may play a role in acquisition. The duration of hand station avoidance was related to the outcome of the previous trial but did not impact the following trial. Dolphins did not avoid the hand station longer as trials progressed, indicating that they may be resilient following failures. Finally, providing small reinforcement magnitudes for attempting the behaviour did not clearly promote successful beaches but also did not seem to hinder success.

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