Temporary behavioral responses to playbacks by a pest parrot and implications for management

Running Head: Playback responses in a pest parrot

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Abstract

Human-wildlife interactions continue to increase due to anthropogenic disturbances, with some interactions resulting in conflict. Leveraging a taxa's bias for a particular sensory cue is a promising management avenue for reducing the potential and realized negative consequences of human-wildlife conflict. For instance, many avian species heavily depend on acoustic communication, and acoustic cues can provide opportunities to reduce conflict with various avian species. The monk parakeet (*Myiopsitta monachus*) is a gregarious parrot native to South America that has established populations worldwide and is considered an urban and agricultural pest in parts of its native and introduced ranges. We conducted playback experiments with a captive population of monk parakeets to evaluate auditory cues that may be useful for designing management protocols. Our experiment evaluated the efficacy of two stimuli: predator vocalizations as potential repulsion and conspecific vocalizations as potential attraction stimuli for parakeets. We measured two responses: (1) categorical group-level behavioral responses and (2) time to cease vigilance and return to behavior prior to playback. In the repulsion playbacks, monk parakeets were repelled by predator vocalizations in 80% of trials and took longer to cease vigilance and return to baseline behavior compared to attraction playbacks. In the attraction playbacks, monk parakeets exhibited vigilant behavior and weak or no attraction to the stimulus, with attraction only being observed in 10% of trials. Our results demonstrate that predator playbacks may be particularly useful for completing management objectives, such as temporary removal from a location.

Keywords

Playback experiments, human-wildlife conflict, behavior, management, avian pests, *Myiopsitta monachus*

Introduction

Anthropogenic disturbances and policies, including changes in human land use, continue to alter ecosystems worldwide. These disturbances are bringing humans and wildlife into more frequent and novel forms of contact, leading to changes in wildlife behavior. For example, disturbances have been found to increase species' nocturnal activity (Gaynor et al., 2018; Wilson et al., 2020) as well as species mortality and habitat loss (Hill et al., 2020; Hoekstra et al., 2004; Kennedy et al., 2019). Disturbances can also alter ecological and evolutionary processes in cities, for instance, by changing landscape heterogeneity that in turn influences resource availability and biodiversity (Des Roches et al., 2021; Schell et al., 2020). These impacts on various species, and the associated human-wildlife conflict, have prompted several management strategies to reduce the negative consequences that may arise from human-wildlife interactions, including indirect practices such as building fences to exclude wildlife from specific areas as well as direct approaches such as lethal management (Khorozyan & Waltert, 2019; Wilkinson et al., 2020). These strategies can potentially resolve the conflict presented (e.g., successfully deterring a species from entering an area); however, the ecological response and effectiveness of implemented strategies are important to consider for both direct and lateral impacts, for example, when constructing fences for the exclusion of particular species (Jones et al., 2018; Wilkinson et al., 2021). Moreover, evaluating the effectiveness of management strategies is crucial for adequately preventing and resolving current human-wildlife conflict consequences (Treves et al., 2006), which may be achieved by integrating an experimental approach (Enck et al., 2006; Richardson et al., 2020; Walters & Holling, 1990).

Recently, researchers have highlighted the benefits of incorporating sensory ecology into management policies. These benefits can include reducing harm to wildlife and predicting how wildlife will respond to environmental change (Elmer et al., 2021). Management strategies built around a species' sensory ecology focus on a particularly relevant sense of the target species and can function as repulsive or attractive signals that cause animals to avoid or gather in areas for specific management-related activities. For example, olfactory cues like wolf urine can stimulate avoidance behavior in deer (Chamaillé-Jammes et al., 2014; Osada, Miyazono, & Kashiwayanagi, 2014), while visual cues, such as changes in lighting or the use of predator models, can cause target species to alter their foraging strategies and overall activity (e.g., black-capped chickadees (*Poecile atricapillus*) (Arteaga-Torres, Wijmenga, & Mathot 2020); ship rats (*Rattus rattus*) (Farnworth et al., 2020)). Moreover, acoustic cues have been used to address management problems for particularly problematic populations via broadcasting biologically relevant sounds to influence reproduction (e.g., bark beetles (Coleoptera: Curculionidae) (Hofstetter et al., 2014)) or using acoustic deterrents, such as underwater speakers, to influence movement (e.g., fish (Putland & Mensinger, 2019)). More generally, acoustic cues have been used to investigate behaviors such as territoriality (Frostman & Sherman, 2004; Heinsohn, 1997; Reif et al., 2015), vocal discrimination (Searcy, Nowicki, & Hughes, 1997; Searcy et al., 2002), and anti-predator responses (Adams & Kitchen, 2020; Bshary, 2001). With many species attuned to auditory cues for their ecology (e.g., primates (Ghazanfar & Santos, 2003), birds (Marler & Slabbekoorn, 2004)), auditory cues provide useful opportunities for nonlethal and widespread management strategies that may reduce human-wildlife conflict.

Natural auditory stimuli, such as vocal signals, are easy to record and broadcast to implement population-level management strategies. These recorded stimuli can be used for two types of management goals. First, repulsive signals can deter individuals from an area where they are unwanted, such as deterring birds from buildings (Boycott et al., 2021) and reducing crop damage on agricultural lands (Mahjoub, Hinders, & Swaddle, 2015; Werrell et al., 2021). Second, attraction signals can encourage individuals to move to an area where the presence of those animals is desired, including inciting individuals to visit and remain in specific habitat patches (Buxton, Ward, & Sperry, 2018; DeJong et al., 2015). With these advances in implementing biologically relevant auditory cues via playback experiments, auditory cues can readily be used as a management approach, particularly when designing management strategies to control avian pests (Berge et al., 2007; Budka et al., 2019; Depino & Areta, 2019; Khan et al., 2011).

The strong foundation of playback experiments provides a robust framework for continuous assessments of how auditory stimuli may contribute to alleviating human-avian conflict, particularly in geographically widespread species. A prime example of widespread avian species that can pose problems for human populations are parrots (Psittaciformes), a species-rich taxon with global distribution (Calzada Preston & Pruett-Jones, 2021; Davies et al., 2007; Kosman et al., 2019; Vergara-Tabares et al., 2020) that have become increasingly established in non-native ranges (Joseph, 2014). As parrot species distributions change with increasing urbanization (Huang et al., 2019; Liu et al., 2020) and movement via the pet trade (Edelaar et al., 2015; Martin, 2018; Pires, 2015), parrots are often coming in close contact with humans. Human-parrot conflict increases as parrots settle in or near human-modified habitats like farms or suburban/urban greenspaces (de Matos Fragata et al., 2022; Menchetti & Mori, 2014), with ~44% of parrot species using croplands as habitat (Barbosa et al., 2021). These conditions make parrots opportune to explore how integrating auditory stimuli can alleviate not only human-parrot conflict but human-wildlife conflict more generally.

The monk parakeet (*Myiopsitta monachus*) has become one of the most widely distributed parrot species (Calzada Preston & Pruett-Jones, 2021), making them a well-suited species to experimentally test approaches that may alleviate human-wildlife conflict. Monk parakeets are gregarious parrots native to South America and have been introduced in over 20 countries in North America, Europe, Africa, Asia, and at least four Caribbean islands as a byproduct of the pet trade (Avery et al., 2020; Burgio, Rubega, & Sustaita, 2014; CABI, 2010; Hobson, Smith-Vidaurre, & Salinas-Melgoza, 2017). Monk parakeets build communal and colonial nests that range in size, with large multi-chambered nests hosting dozens of pairs (Avery et al., 2002; Bucher et al., 1990; Eberhard, 1998;). Conflict between humans and monk parakeets typically manifests in three ways: (1) economic and safety hazards in urban areas, (2) agricultural impacts, and (3) human health concerns. Following their establishment of new populations, monk parakeets have established nests throughout the urban sprawl on artificial structures as varied as power poles, electricity substations, silos, and fire escapes (Avery & Lindsay, 2016), introducing economic costs and safety concerns for humans (Avery et al., 2002; Stafford, 2003). In addition to their role as an urban pest, monk parakeets' propensity to inhabit changing landscapes and consume a wide variety of food resources (Bucher & Aramburú, 2014; Postigo et al., 2021) has also led them to become agricultural pests in parts of their native and introduced ranges (Davis, 1974; MacGregor-Fors et al., 2011; Mott, 1973; Senar et al., 2016; Stafford, 2003). For instance, damage in Barcelona ranges from 0.4% to 37% crop loss, depending on the particular crop (Senar et al., 2016). Lastly, recent research indicates that monk parakeets may serve as a reservoir for zoonotic diseases in some areas (Morinha et al., 2020), introducing a concern for human health; however, this is not widely observed (Ortiz-Catedral et al., 2022). As a result of these concerns and conflicts, monk parakeets have become a management priority in many areas.

Thus, ecologically informed techniques for managing these parrot populations are essential to mitigate conflict among human and monk parakeet populations.

Here, we explore group-level behavioral responses of a captive population of monk parakeets to biologically relevant auditory stimuli and discuss our findings within a wildlife management context. We evaluated two auditory cues that we expected to serve as either repulsion (predator vocalizations) or attractive (conspecific vocalizations) stimuli, as well as control stimuli (vocalizations from a common bird we expected to serve as neither repulsive nor attractive). We hypothesized that (1) predator playbacks would result in the repulsion of the captive group away from the auditory source in accordance with the literature on prey responses to predator stimuli (Hettena, Munoz, & Blumstein, 2014; Lönnstedt et al., 2012; Smith et al., 2017) and (2) conspecific playbacks would result in the attraction of the captive group towards the auditory source, in line with previous work that used conspecific vocalizations to attract individuals of a focal species and to attract focal species to specific patches (Ahlering et al., 2010; Lewis, Williams, & Gilman, 2021). We then discuss how our results could help inform different management strategies and goals for avian pest species.

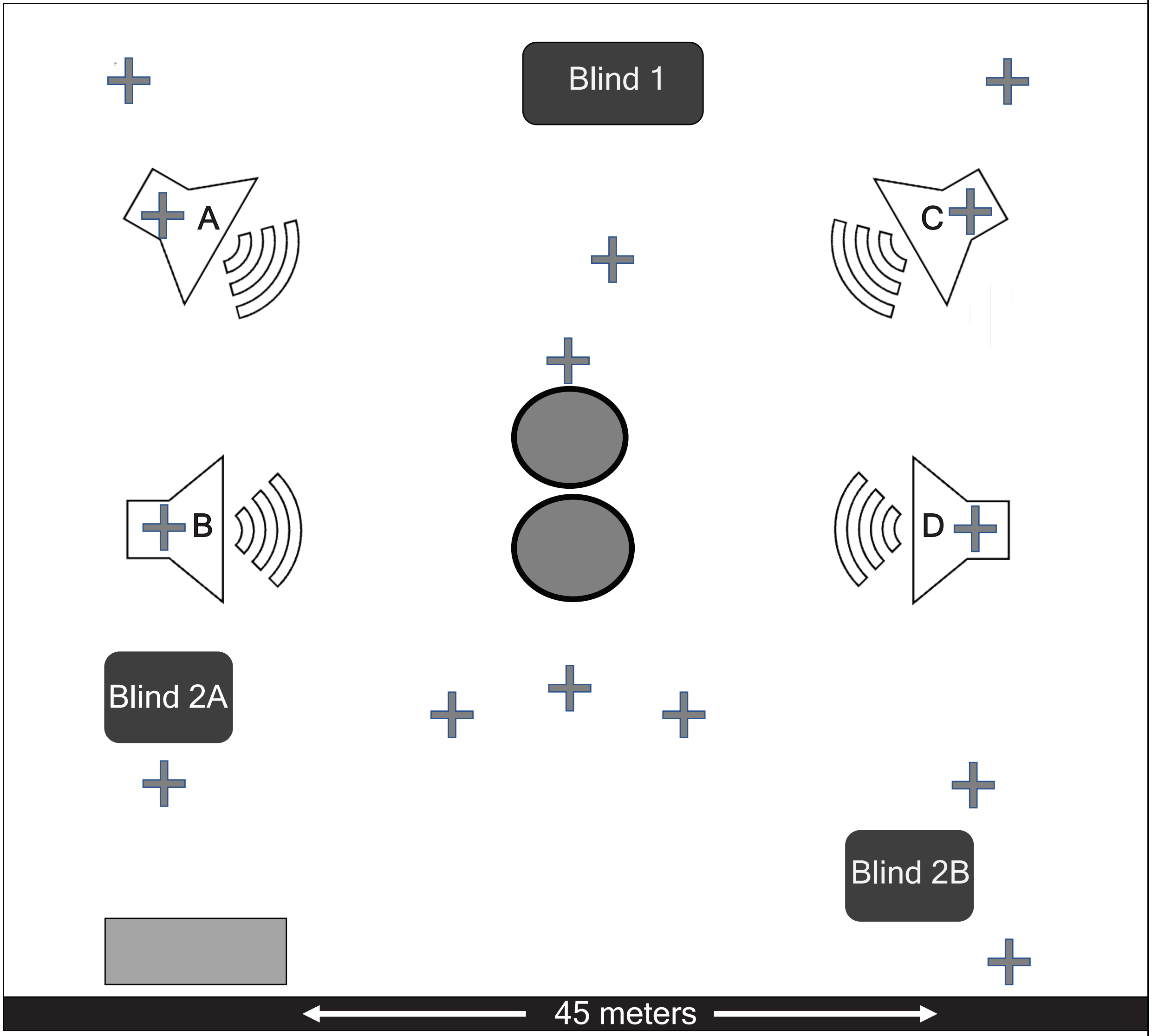
Methods

Study Species and Location

We conducted this study on a captive population of monk parakeets (*n* = 20) in Gainesville, Florida at the USDA Wildlife Services National Wildlife Research Center Florida Field Station from April to July 2021. This population of monk parakeets was captured just prior to our study period (January – March 2021) by the USDA National Wildlife Research Center from feral populations throughout Southern Florida. This population was held in a large 2,025 m^2 outdoor semi-natural flight pen (Figure 1). Using newly caught feral monk parakeets in a semi-natural flight pen allows us to (1) observe behavioral responses that would likely occur in natural settings where these playbacks would be used as this population was only in captivity for a month prior to our experiment and (2) maintain constant group size to consistently measure behavioral responses in our captive population. All experiments were approved by the University of Cincinnati (IACUC protocol #AM02-19-11-19-01) and the National Wildlife Research Center (Quality Assurance protocol #3203).

Figure 1

Overview of the flight pen at the USDA Wildlife Services National Wildlife Research Center Florida Field Station.



Note. Positions for speakers during playback trials are shown as outlined speakers with locations A, B, C, and D. Crosses and boxes represent perch areas throughout the flight pen, and circles represent trees. Blinds are locations where observers are located during playback sessions.

Playback Stimuli

We used three playback stimuli to conduct our experiments: a predator call to test for repulsion, a conspecific call to test for attraction, and a control to ensure that attraction and repulsion patterns were not due to our playback setup or speaker (see the following paragraphs for details on playback file creation). For our predator playback, we used vocalizations from a local predator, the red-tailed hawk (*Buteo jamaicensis*). For our conspecific playback, we used vocalizations from monk parakeets that were strangers to the captive group. For our control playback, we used vocalizations from a local bird species, the mourning dove (*Zenaida macroura*). We maintained a consistent volume for the playback stimuli across all trials. We created all playback tracks in Raven Lite version 2.0.1 (Bioacoustics Research Program 2014, Cornell Lab of Ornithology) and used randomization in RStudio version 4.1.0 (R Core Team, 2021) to choose the variant of each playback track used in each trial.

Both red-tailed hawk and mourning dove vocalizations were selected for their biological relevance as predatory and non-predatory species, respectively, and their common occurrence in Florida. Neither of these species was abundant around the flight pen, which lessened the chance of attracting local birds when playing conspecific calls and confounding parakeets' responses to our experimental stimuli. Despite the low abundance of both species near our experimental setup, we expected that the newly caught group of monk parakeets would reliably respond to the respective calls, since these species are both abundant where the feral parakeets were captured from wild populations in Southern Florida. We downloaded screech calls of adult red-tailed hawks and perched songs of adult mourning doves from xeno-canto, a non-profit website that stores recordings of bird vocalizations uploaded by recordists worldwide (Planqué & Vellinga, 2008; Vellinga & Planqué, 2015). We chose recordings that did not contain any background vocalizations of conspecifics or heterospecifics. We chose three unique files per species and selected the first 30 seconds of each file to create a playback track. This method resulted in three unique tracks (exemplars) per stimuli. Predator playback tracks contained four to ten vocalizations per track, and control playback tracks contained three vocalizations per file (exemplars). We did not edit the number of vocalizations after selecting the first 30 seconds of each file as we wanted to accurately replicate vocalizations evoked in natural settings. In each repulsion and control trial, we randomly selected one of the three exemplars to broadcast to the captive parakeets.

For conspecific vocalizations, we randomly selected non-native (*n* = 3) and native (*n* = 3) range monk parakeet contact calls collected in previous studies (Smith-Vidaurre, Araya-Salas, & Wright, 2020; Smith-Vidaurre, Perez-Marrufo, & Wright, 2021). We used contact calls as our stimuli because parrots often use these vocalizations to maintain auditory contact within pairs and flocks (Bradbury & Balsby, 2016). We included non-native calls in addition to native calls to reduce the chances of novelty responses, as non-native calls should be less novel to birds from a non-native population. In addition, when selecting non-native range calls, we controlled for biases in behavioral responses to familiar birds by selecting monk parakeet contact calls recorded outside of Florida, but still within the United States of America, which allowed us to present calls of individuals that were likely unfamiliar to the captive birds. We created three unique playback tracks (exemplars) for each native and non-native range call. Each track represents a unique individual. For each playback track, we randomly selected one call and repeated the selected call ten times, separated by three-second gaps to simulate natural calling behavior (Hobson et al., 2015). Each conspecific playback was 30 seconds long and contained nine replicates of each exemplar. In each conspecific trial, we randomly selected one of these playback tracks to broadcast to the captive parakeets.

All playback tracks contain vocalizations from unique individuals. The predator/control playback tracks are similar in duration to the conspecific playback tracks. The difference between the predator/control tracks and the conspecific tracks is that we used different vocalizations for the predator/control tracks but repeated one vocalization for the conspecific tracks (Figure S1).

Experiment and Setup

We conducted playback sessions between 09:00 and 18:00 using a wireless speaker (JBL Charge 4 Wireless speaker). We randomized the speaker's placement to four locations within the flight pen to reduce the probability of habituation to playback stimuli (Figure 1). We also randomized the order of playback stimuli (predator, conspecific, and control) and the track used per trial to reduce the chances of habituation. Each playback trial was separated by a minimum of five hours to reduce the chance of habituation (we conducted most trials with about 48 hours between playback sessions).

Before playback sessions, observers verified that red-tail hawks and mourning doves were not present in the vicinity of the flight pen. To maximize the chances that the parakeets heard the selected playbacks, we did not begin a playback session until we observed low levels of parakeet activity in the flight pen (e.g., low call rates, individuals perching in trees behaving non-agonistically). When activity was low, we set up the speaker in the pre-designated, randomized location. After setting up the speaker, the observer returned to their respective blind, and we waited at least fifteen minutes to begin playback sessions. If birds did not return to baseline behavior, we waited longer until birds returned to baseline behavior or low activity levels were observed. We removed the speaker following each trial to reduce damage from monk parakeets and recharge speakers.

Data Collection

During each trial, two observers recorded the behavioral response of the birds, one in blind 1 and one in either blind 2A or 2B (Figure 1). We observed group-level behavior five minutes prior to each playback session to establish baseline group-level behavior. We recorded two responses to playbacks for at least 50% of the captive group: (1) categorical group behavioral responses; (2) the time it took birds to cease response behavior and return to baseline behavior (latency in seconds). We then used group responses to score the overall flight responses observed.

To measure group responses, we scored group-level behaviors on a scale of 0-4: (0) no response (birds continue their activities without becoming vigilant); (1) vigilant (birds stop the behaviors they were performing, do not move, and become alert); (2) minor movement (birds become alert and there is slight movement in trees (e.g., hopping between branches)); (3) less than 50% fly (≤10 birds take flight and become vigilant); (4) more than 50% birds fly (>10 birds take flight and become vigilant). We used the animal behavior data collection app Animal Observer (version 1.0, Dian Fossey Gorilla Fund International 2012; van der Marel et al., 2022) to score responses. Observers narrated into the voice recorder function of Animal Observer to record the behavior of visible birds starting 5 min prior to the playback to establish baseline behavior and ending narration 5 min after the playback, or until birds returned to baseline behavior. Observers also narrated when the playback session began, when the playback session ended, and when the majority of the birds (>50% of the captive group) resumed baseline behavior after the playback ended. Narrations should not alter behaviors of our captive group due to (1) habituation to hearing human voices due to radio communication throughout the field season, (2) blind 1 is a large, closed structure which sound cannot easily travel through, 3) blinds 2A and blinds 2B are placed where parakeets rarely frequent, and (4) observers spoke quietly enough for birds to not hear the reporting of observations. Upon completion of the playback session, we determined the latency of all responses as the difference between the playback end time and the time at which the majority of birds resumed baseline behavior. We averaged latency measurements between blind 1 and the second blind we used (either blind 2A or 2B, see Figure 1), depending on which blind was randomly selected for observation.

Data Analysis

We used mixed models to examine the effect of the three different playback stimuli (predator, conspecific, control) on group behavior and latency (Figure S2). We included playback stimuli and trial as independent factors. We included trial (*n* = 5) to test for the effect of habituation on both group response and latency. We used playback track and observer as random factors in the group response model but only track as a random factor in the latency model. To begin model selection, we tested for the effect of each random factor by sequentially excluding one of the random factors. We then compared the AICc values of the different random effect models using the *performance* package (Lüdecke et al., 2021) and selected the model that best fits the data. We did not find a significant effect of observers on the model, indicating that this random factor would not bias our results. Therefore, we did not run a Z-test to control for observer bias and excluded observer for further analyses. We then built four models to examine which independent variables fit our data: a full model with all independent variables, two models where either playback stimuli or trial were omitted, and a null model where both independent variables were omitted (Figure S2). We fit these models to the data again with the *performance* package

(Lüdecke et al., 2021) and selected the model with the lowest AICc value. After model selection for both group responses and latency models, we tested for significant differences between the best fitted and null model from the *lmtest* package (Zeileis & Hothorn, 2002) using likelihood ratio tests (LRT). When the best-fitted model was significantly different from the null model, we performed an LRT to investigate the effect of that independent variable by comparing the best-fitted model with the independent variable of interest to a model without that independent variable. If the independent variable showed a significant effect, we assessed the statistical significance using Tukey's Honest Significant Differences.

We first examined the effect of the playback stimuli (predator, conspecific, control) on group behavior. Group behavior followed an ordinal distribution, so we used a cumulative link mixed model (CLMM) from the *ordinal* package (Christen, 2019). Then, since latency was a continuous variable, we used the *car* and *MASS* packages (Fox & Weisberg, 2019; Venables & Ripley, 2002) to examine which distribution best fits the data. We found that a normal probability distribution best fits our latency data, so we analyzed latency using linear mixed models (LMMs) in the *lme4* package (Bates et al., 2015). We checked for heteroscedasticity and overall model performance using the performance package. We reported the mean and standard deviation for latency for each playback stimulus below. Finally, we derived flight responses from group behaviors using a scale from 1 to -1, with the sign contingent on whether it was a repulsion behavior (positive) or an attraction behavior (negative). Flight responses were given a score based on these criteria: (0): no behavior, vigilant, or minor movement; (± 0.5): less than 50% of birds fly; (± 1): more than 50% of birds fly. To examine differences in flight behaviors among the playback stimuli, we analyzed the flight responses using Kruskal-Wallis' one-way analysis of variance followed by a pairwise comparison using Wilcoxon's rank-sum test.

We completed all analyses in RStudio v.4.1.0 (R Core Team, 2021). We made all plots using the *ggplot2* package (Wickham, 2016) and aestheticized plots (e.g., adding species icons) in Adobe Illustrator (Adobe Illustrator, Adobe Inc.).

Results

We conducted 20 playback trials: 5 repulsion playbacks (predator calls), 10 attraction playbacks (conspecific calls: 5 non-native range and 5 native range), and 5 control playbacks (mourning dove calls). We assessed whether playback stimuli influenced group response, latency, and flight response.

How Do Monk Parakeets Behaviorally Respond to Playbacks?

We found significant differences in group response among playback stimuli (LRT: $\Lambda = 17.70$, $p < 0.001$; Table 2). Monk parakeets exhibited significant differences in group responses to predator playbacks compared to conspecific playbacks (Tukey's $p < 0.05$) and control playbacks (Tukey's $p < 0.05$) (Table 2, Figure 2A and 3). In response to predator playbacks, monk parakeets exhibited more than half-flock dispersal for 60% of trials, at least half-flock dispersal for 20% of trials, and vigilance for 20% of trials (Figure 3). We did not find significant differences in group responses to conspecific playbacks compared to control playbacks (Tukey's $p = 0.15$) (Table 2, Figure 2A and 3). In response to conspecific playbacks, monk parakeets exhibited half-flock dispersal in 10% of trials, with no change in behavior, minor movement, and vigilance making up 20%, 10%, and 60% of trials, respectively (Figure 3). In response to control playbacks, monk parakeets exhibited vigilance for 40% of trials and no change in behavior for 60% of trials (Figure 3). We found no evidence that monk parakeets habituated regarding group response to playback stimuli as trial was not included in the model with the lowest AICc value (Table 1, Figure S3).

Table 1

AIC model selection results for the effects of playback stimuli on group response and latency.

Response Variable	**Variable(s)**	**K**	**LL**	**AICc**	**Delta**	**Weight**	**R^2**
Group response	Playback Stimuli + Trial	11	-15.14	85.28	24.82	< 0.001	NA
	Playback Stimuli	**7**	**-18.56**	**51.12**	**0**	**0.99**	**NA**
	Trial	9	-25.88	87.76	27.31	< 0.001	NA
	Null	5	-27.41	69.11	8.65	0.01	NA
Latency	**Playback Stimuli + Trial**	**9**	**-59.16**	**154.32**	**0**	**0.995**	**0.71**
	Playback Stimuli	5	-75.33	164.95	10.63	0.005	0.64
	Trial	7	-75.78	174.89	20.58	< 0.001	0.09
	Null	3	-92.02	191.55	37.23	< 0.001	< 0.001

Note. Exemplar was included as a random factor for each model. K is the number of estimated parameters for each model, LL is the log-likelihood of each model, AICc is the second-order AIC, Delta is the difference in AIC score between the best model and the model being compared, Weight is the weight of evidence in favor of a given model, and R^2 is the proportion of variance in the dependent variable that can be explained by the selected independent variable(s). R^2 is not available for group response.

Table 2

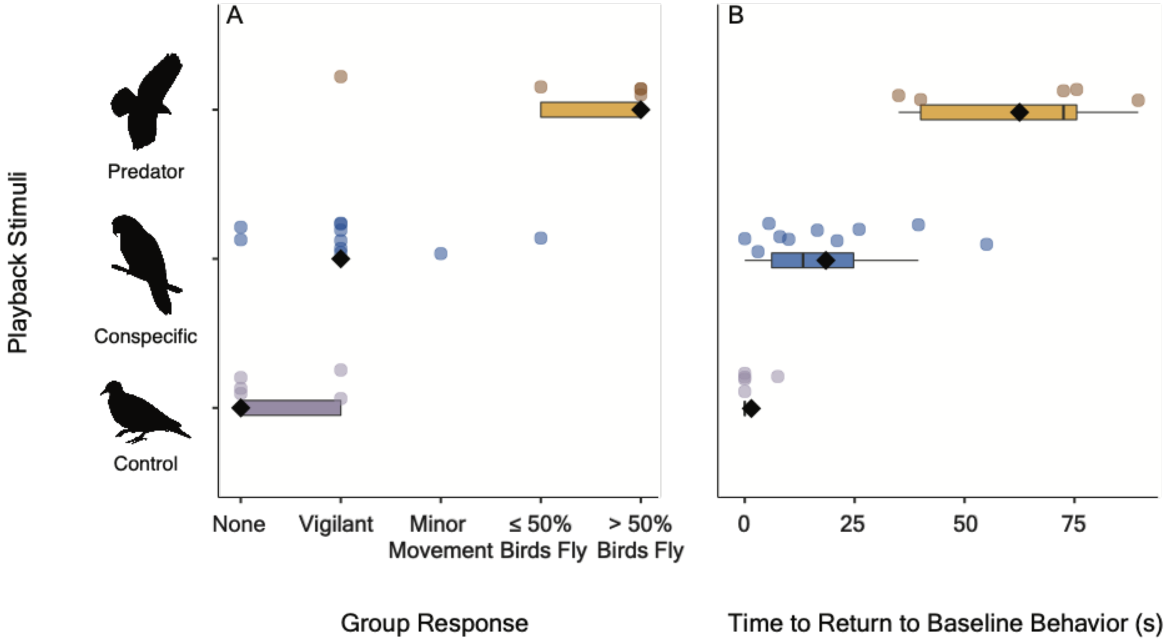
95% confidence interval results for effects of playback stimuli on group response and latency.

	Group response	**Latency**
Family	Ordinal	Gaussian
Intercept	NA	(-2.86, 26.06)
Conspecific playback	(-0.16, 6.78)	**(2.48, 31.42)**
Predator playback	**(2.32, 16.68)**	**(44.29, 77.71)**

Note. 95% confidence interval is reported as (LL, UL) such that LL = lower limit for 95% confidence interval and UL = upper limit for 95% confidence interval. Intercept is not available for group response.

Figure 2

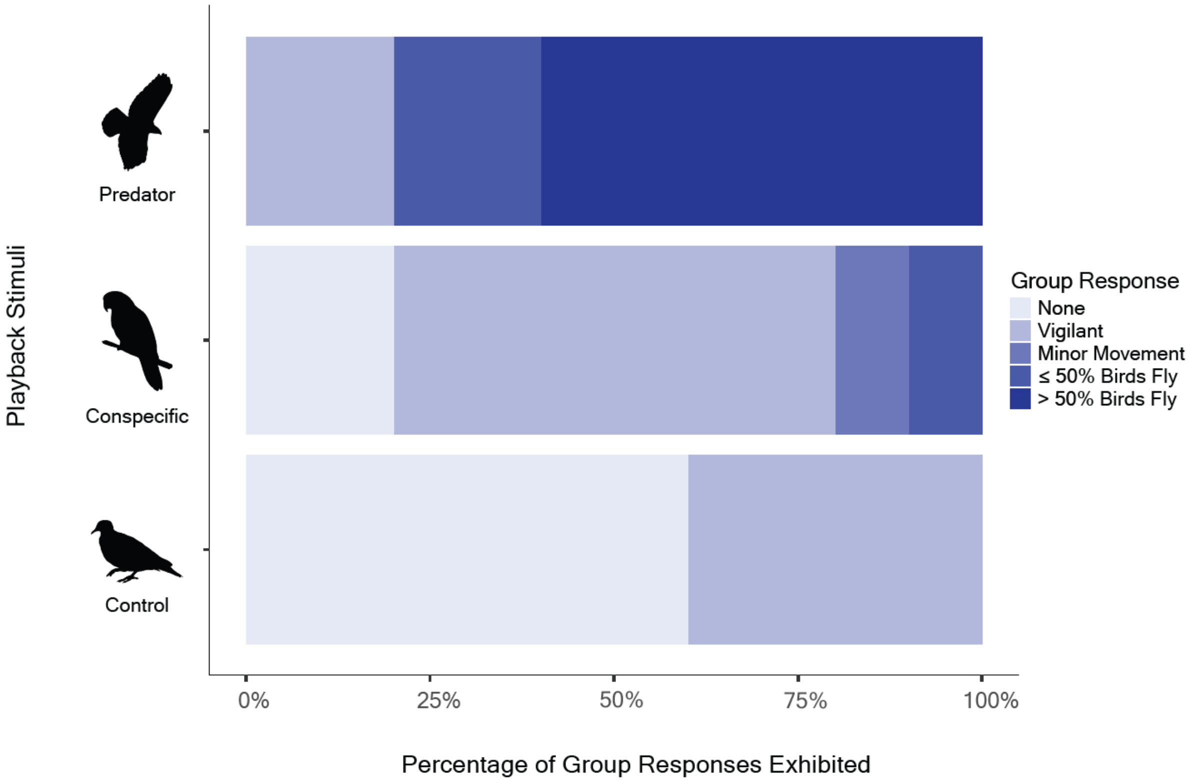
Behavioral responses to playback stimuli.



Note. In panel A, group-level responses are on the x-axis. In panel B, the time to return to baseline behavior in seconds (latency) is on the x-axis. Repulsion (predator – red-tailed hawk, *n* = 5), attraction (conspecific – monk parakeet, *n* = 10), and control (non-predatory – mourning dove, *n* = 5) stimuli are on the y-axis. Measurements are shown in box plots with the median (panel A) and mean (panel B) shown as black diamonds. Error bars indicate 95% confidence intervals.

Figure 3

The percentage of group responses in response to playback stimuli.



Note. Stronger group responses are shown in darker blue and weaker behavioral responses in lighter blue.

How Long do Monk Parakeets Take to Return to Baseline Behavior?

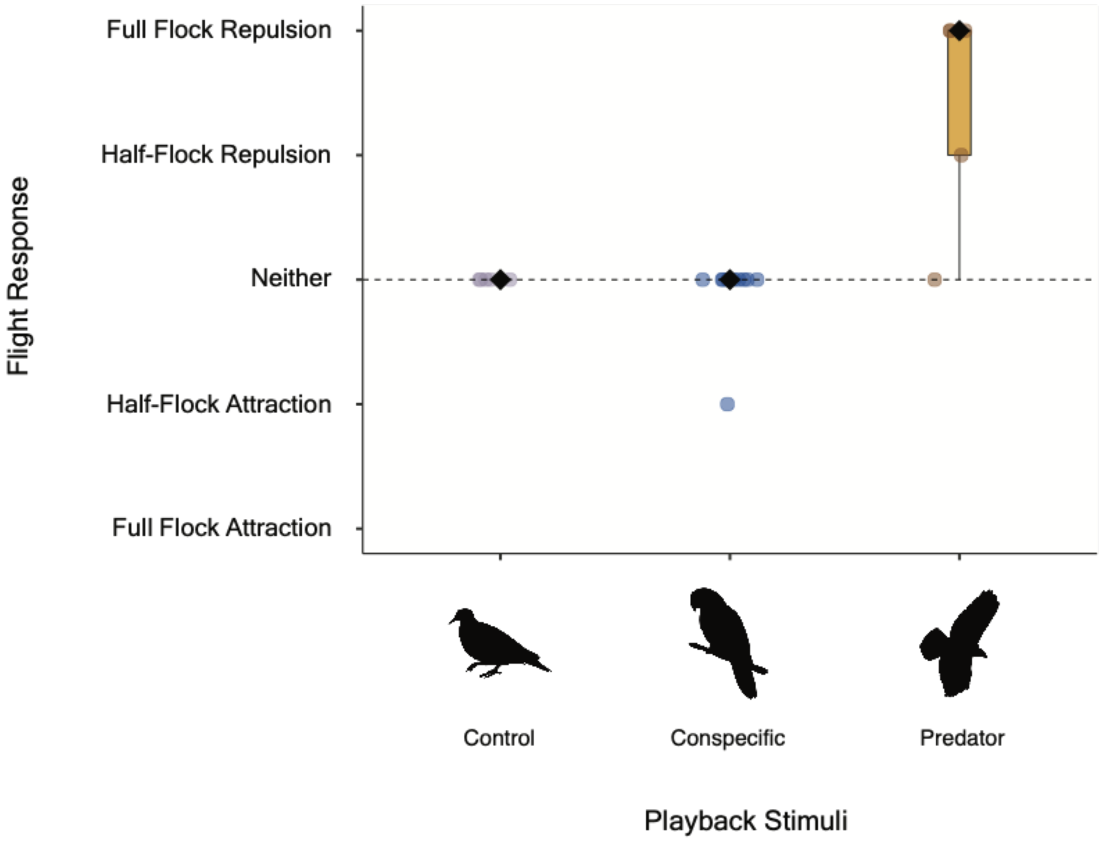
The model that best explained latency included playback stimuli and trial (LRT: $\Lambda = 30.70$, $p < 0.001$; Table 1). We found significant differences in latency among playback stimuli (LRT: $\Lambda = 28.22$, $p < 0.001$; Fig. 2B), but we did not find a significant effect of trial on latency (LRT: $\Lambda = 8.64$, $p = 0.07$; Table 1, Figure S4). Average latency to return to baseline behavior in response to predator playbacks (62.50 ± 23.77 s) was longer and had more variation than conspecific (18.50 ± 17.56 s; Tukey's $p < 0.01$) and control (1.50 ± 3.35 s; Tukey's $p < 0.001$) playbacks (Table 2, Figure 2B). Unlike overall group response, the effect of conspecific playbacks on latency to return to baseline behavior was not significantly different compared to control playbacks (Tukey's $p = 0.18$; Table 2, Figure 2B), although the confidence interval did not include zero (Table 2).

Which Playback Stimulus Produced a Flight Response?

We found significant differences in flight responses (Kruskal-Wallis's $p < 0.01$) and that the flight response of predator playbacks was more consistent than conspecific playbacks (Figure 4). Predator playbacks elicited repulsion behavior in 80% of playback trials and showed significant differences in flight response when compared to conspecific (Wilcoxon's $p < 0.05$) and control flight responses (Wilcoxon's $p = 0.01$). Unlike predator playbacks, conspecific playbacks only produced the predicted behavior (attraction) in 10% of trials (Figure 3). Conspecific playbacks showed no significant difference in flight response compared to the control playbacks (Wilcoxon's $p = 0.57$).

Figure 4

Repulsion and attraction behavior in response to playback stimuli.



Note. Group responses to predator playbacks ($n = 5$), conspecific playbacks ($n = 10$), and control playbacks ($n = 5$) were rescaled and categorized in the context of repulsion and attraction. Predator playbacks showed significant differences in flight response compared to both conspecific and control playbacks. Measurements are shown in box plots with the median indicated by black diamonds. Error bars indicate 95% confidence intervals.

Discussion

The primary objective of this study was to test how different auditory stimuli (predator or conspecific) produced repulsion or attraction behaviors in a captive population of monk parakeets. We found differences in how strongly the parakeets responded to both types of stimuli, which could be important to consider when integrating auditory stimuli into management strategies for this species.

Our results support the hypothesis that predator vocalizations cause flock dispersal away from auditory sources (repulsion). Predator playbacks produced stronger behavioral responses in monk parakeets than conspecific and mourning dove playbacks. Predator playbacks resulted in flight 80% of the time, whereas conspecific playbacks resulted in flight 10% of the time, and mourning dove playbacks never produced flight behavior. Additionally, predator playbacks with few and many vocalizations elicited mostly repulsion behavior and exhibited variation in latency. This variation in latency is likely not due to the number of vocalizations per track but may be a consequence of an individual’s social environment, such as the vigilance of their nearest neighbor (e.g., van der Marel et al., 2021). Overall, our results align with studies that showcase strong behavioral responses to predators in the form of mobbing, movement, and/or vocalizing (Crawford et al., 2022; Dutour, Lena, & Lengagne, 2017; Manser, Seyfarth, & Cheney, 2002; Zuberbühler, 2001). For example, predator playbacks of the sparrow hawk (*Accipiter nisus*) successfully repelled house sparrows (*Passer domesticus*), with no habituation observed after six days of exposure (Frings & Frings, 1967), and playbacks of a peregrine falcon (*Falco peregrinus*) call was also effective at dispersing gulls from Vancouver International Airport (Gunn, 1973). Because of these strong responses, managers seeking to temporarily displace monk parakeets from a specific area may have success using predator calls.

In contrast, our results do not support the hypothesis that conspecific calls attract parakeets to the auditory source, with no significant differences found between the conspecific and control stimuli. We found that conspecific calls resulted in weak or no attraction of parakeets to the stimulus despite support for attraction to conspecific vocalizations across taxa (see Buxton et al., 2020), with half-flock movement towards the auditory source observed only once across all ten playbacks. From a management perspective, our results indicate that conspecific calls may not be effective stimuli to attract parakeets to a specific area, for example, to facilitate trapping. However, other variables may need to be considered when selecting conspecific vocalizations for playbacks, which may affect their effectiveness for management aims. For example, Nocera et al. (2006) showed that, due to a lack of experience, natal dispersers (i.e., juveniles) might be more receptive to conspecific vocalizations. Kelly and Ward (2017) suggested that in yellow warblers (*Setophaga petechia*), site selection via conspecific attraction is more successful when vocalizations from paired males are used, while Connell et al. (2019) suggested that in black-tailed prairie dogs (*Cynomys ludovicianus*), other cues, such as the physical presence of and/or relationship to the caller, may be essential factors to consider for playbacks.

An individual's response to an auditory cue may depend on the social information communicated through vocalizations in a particular social system. For example, monk parakeets may respond to conspecific calls based on their relationship to the caller (Hobson et al., 2015), which has been seen in other birds such as acorn woodpeckers (*Melanerpes formicivorus*) (Pardo et al., 2018), carrion crows (*Corvus corone*) (Wascher et al., 2012), and ravens (*Corvus corax*) (Szipl et al., 2015). Parakeets may also respond based on the locality of the call, which has been observed in rufous-collared sparrows (*Zonotrichia capensis*) (Danner et al., 2011), yellow-naped Amazons (*Amazona auropalliata*) (Wright & Dorin, 2001), and stonechats (*Saxicola torquata*)(Mortega, Flinks, & Helm, 2014). Moreover, monk parakeets exhibit unique vocal signatures in contact calls tied to individual identities, and these individual signatures are simpler in smaller non-native range populations, which suggests that monk parakeets use contact calls to recognize distinct individuals (Smith-Vidaurre, Araya-Salas, & Wright, 2020; Smith-Vidaurre, Perez-Marrufo, & Wright, 2021). Therefore, it may be useful for researchers to explore behavioral responses to familiar or unfamiliar individuals to determine which calls may be best for management purposes.

We did not examine differences in individual responses to playbacks with this study design. However, it can be important to understand how individual characteristics (e.g., sex or age) and social relationships (e.g., partnered with another individual) influence an individual's response to stimuli and how this may influence overall group-decision making for a robust management approach. For example, Kerman (2018) found that male monk parakeets that are risk-aversive while foraging become bolder in the presence of conspecifics, and it has been observed that monk parakeets decrease vigilance effort as flock size increases (South & Pruett-Jones, 2000). Thus, assessing how social context (e.g., flock size) may underlie behavioral responses to external stimuli could be necessary for management success. When managing group-living species such as monk parakeets, it may be important to adjust for population-level differences due to possible individual and group-level behavioral variation as a result of unique ecological pressures (Maldonado-Chaparro & Chaverri, 2021). Future studies should explicitly consider how individual, population, and temporal characteristics, including variation in group size and season, influence responses to sensory cues that may be useful for management.

Management Implications

Our results showcase clear behavioral outcomes based on the playback stimuli used, with no evidence of habituation, that are promising for management purposes. Auditory cues can be used at a very low cost, with little to no ecosystem disturbance, and are readily available. Furthermore, auditory cues may not come with conflicts of interest compared to other forms of management, such as culling via poisons (van Eeden et al., 2017).

Our results show that predator playbacks produced a momentary change in behavior in captive monk parakeets. Predator stimuli may be useful when management objectives require the temporary dispersal of individuals from a small area. For example, once monk parakeets are detected at a site, predator playbacks may help disperse birds and prevent site-specific nest building (Burgio, Rubega, & Sustaita, 2014). When implementing predator playbacks, managers should consider the geographic location of the monk parakeet population to select the appropriate predator(s). In Florida, common avian predators include the red-tailed hawk, red-shouldered hawk (*Buteo lineatus*), and Cooper's hawk (*Accipiter cooperii*), but in other introduced locations such as the Iberian Peninsula, avian predators such as the Eurasian sparrowhawk (*Accipiter nisus*) and Eurasian kestrel (*Falco tinnunculus*) may be more appropriate choices.

When considering playbacks as part of a management plan, the timing of the intervention should also be carefully considered, as the parakeets may be more or less responsive to predator stimuli. For example, monk parakeet site fidelity increases once nests have been established (Dawson Pell et al., 2021), so management interventions could be timed to occur prior to this increased fidelity. Because of this high nest fidelity, it is unlikely that predator playbacks would cause nest and site abandonment once the parakeets have initiated nest building. Although auditory cues alone may not be enough to control a particular group or population, coupling auditory cues with additional management strategies may be powerful for desired outcomes. In this case, it may be useful to leverage an integrated approach, including other currently implemented avian management tools, e.g., frightening devices (Enos, Ward, & Hauber, 2021). For example, in areas where lethal shooting is authorized and safe to implement, using predator playbacks to prompt flocking behavior could help maximize the efficacy of culling as a management tool.

Several variables should be considered when incorporating playback stimuli into management strategies to optimize success and effectiveness: (1) the establishment stage in settlement of non-native populations of monk parakeets (e.g., the arrival of new founders vs more established breeding populations) (Dawson Pell et al., 2021), (2) the estimated flock-size of the focal group of monk parakeets (South & Pruett-Jones, 2000), and (3) the ecological and/or management purpose of the playback. For instance, strategies resulting in temporary repulsion could be used when the return of the focal species is an acceptable management outcome, but methods that facilitate permanent deterrence would be necessary to ensure that a focal species will not return to a given area. These factors will influence the type of playback a manager is interested in using (e.g., heterospecific vs conspecific) and, consequently, the efficacy of the selected playback to alter the behavior of monk parakeets in a manner deemed useful for management purposes.

Conclusion

Our experiments show the potential for repulsion stimuli to be an effective tool for some management plans for monk parakeet populations, where the goal is to temporarily displace a flock of parakeets and induce flight and vigilance behaviors. Our results re-emphasize the importance of informing management with data from experiments. These results can then be framed to recommend options managers can consider when managing monk parakeet populations and other avian populations that rely on ecological information in the form of auditory cues.

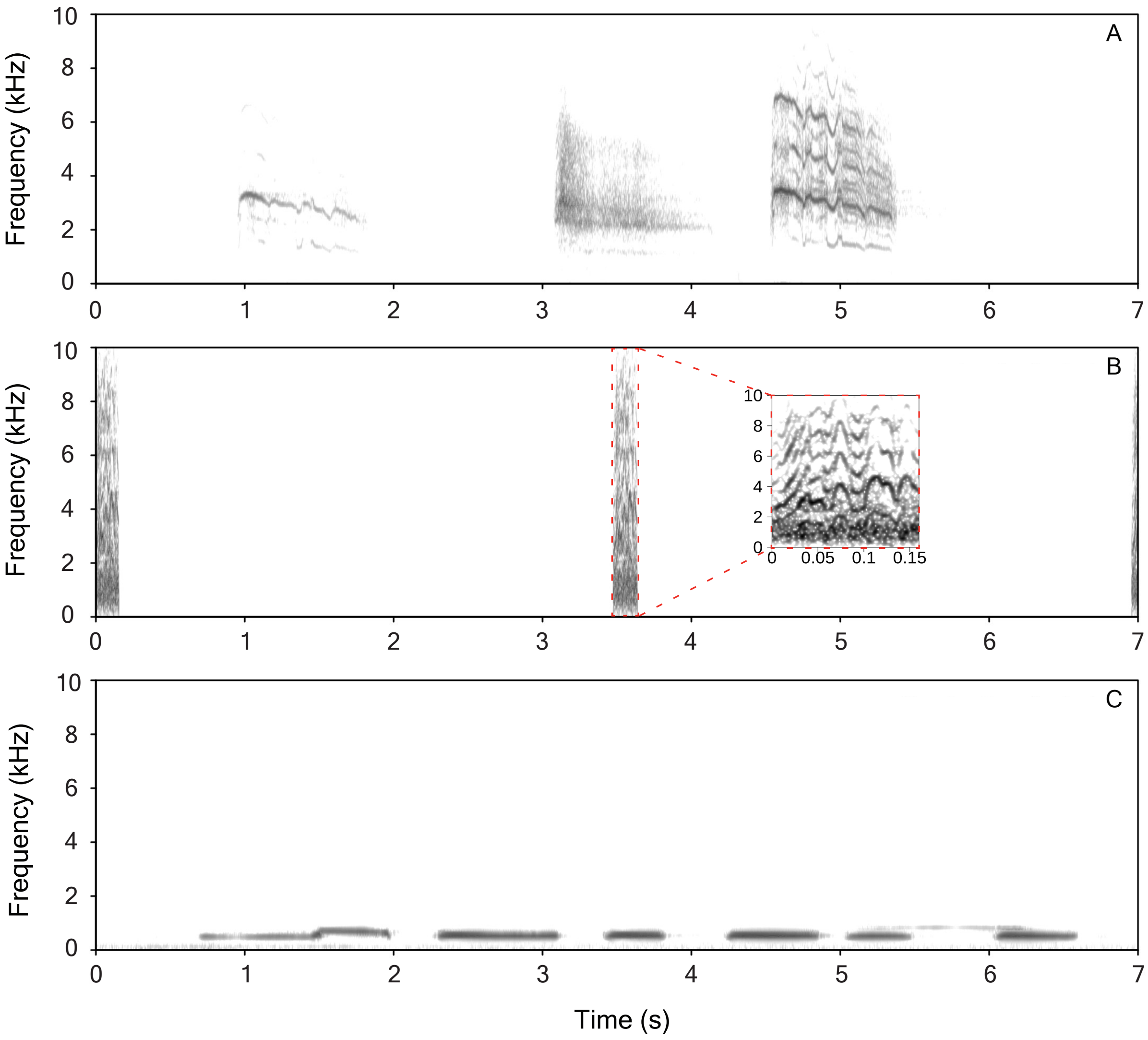
Acknowledgements

We acknowledge that the fieldwork for this project was conducted on the ancestral and unceded lands of the Seminole and Timucua people. We acknowledge that the majority of writing and data analysis was completed at UC Berkeley which sits on the ancestral and unceded lands of the Ohlone people. These lands of what is now considered Gainesville, Florida and Berkeley, California continue to be great importance to their respective Indigenous people, and we recognize that we benefit from the use and occupation of these lands. We would like to thank the USDA staff, especially Eric Tillman, John Humphrey, Danyelle Sherman, and Palmer Harrell, for their assistance and support. We would like to the thank Christine Wilkinson, Tal Caspi, Yasmine Hentati, Lauren Stanton, Samantha Kreling, Brian Stokes, and Stavi Tennenbaum for feedback on an early version of this manuscript. We would also like to thank the editor and two anonymous reviewers for comments that improved this manuscript. During preparation of this work, COE was supported by University of California, Berkeley's Chancellor Fellowship and the National Science Foundation Graduate Research Fellowship under Grant No. DGE-2146752, GSV was supported by an NSF Postdoctoral Research Fellowship (grant number 2010982), and XF and EAH was supported by NSF IOS 2015932. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. The findings and conclusions in this publication have not been formally disseminated by the U.S. Department of Agriculture and should not be construed to represent any agency determination or policy. This research was supported in part by the U.S. Department of Agriculture, National Wildlife Research Center.

Supplementary Materials

Figure S1

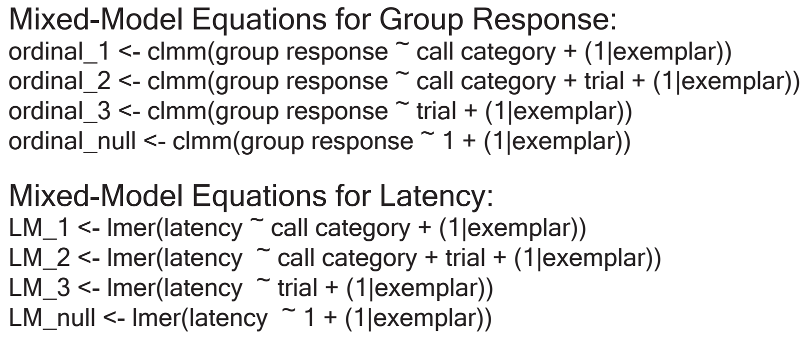
Spectrogram images of playback files.



Note. A multi-panel comprised of spectrograms for the first seven seconds of each call category. Panel A displays calls from the predator vocalization (red-tailed hawk). Panel B displays calls from the conspecific vocalization (monk parakeet). Panel C displays a call from the control vocalization (mourning dove). Frequency in kilohertz (kHz) is shown on the y-axis and time in seconds is shown on the x-axis.

Figure S2

Mixed model equations used to examine the effect of playback stimuli on group response and latency.



Mixed-Model Equations for Group Response:

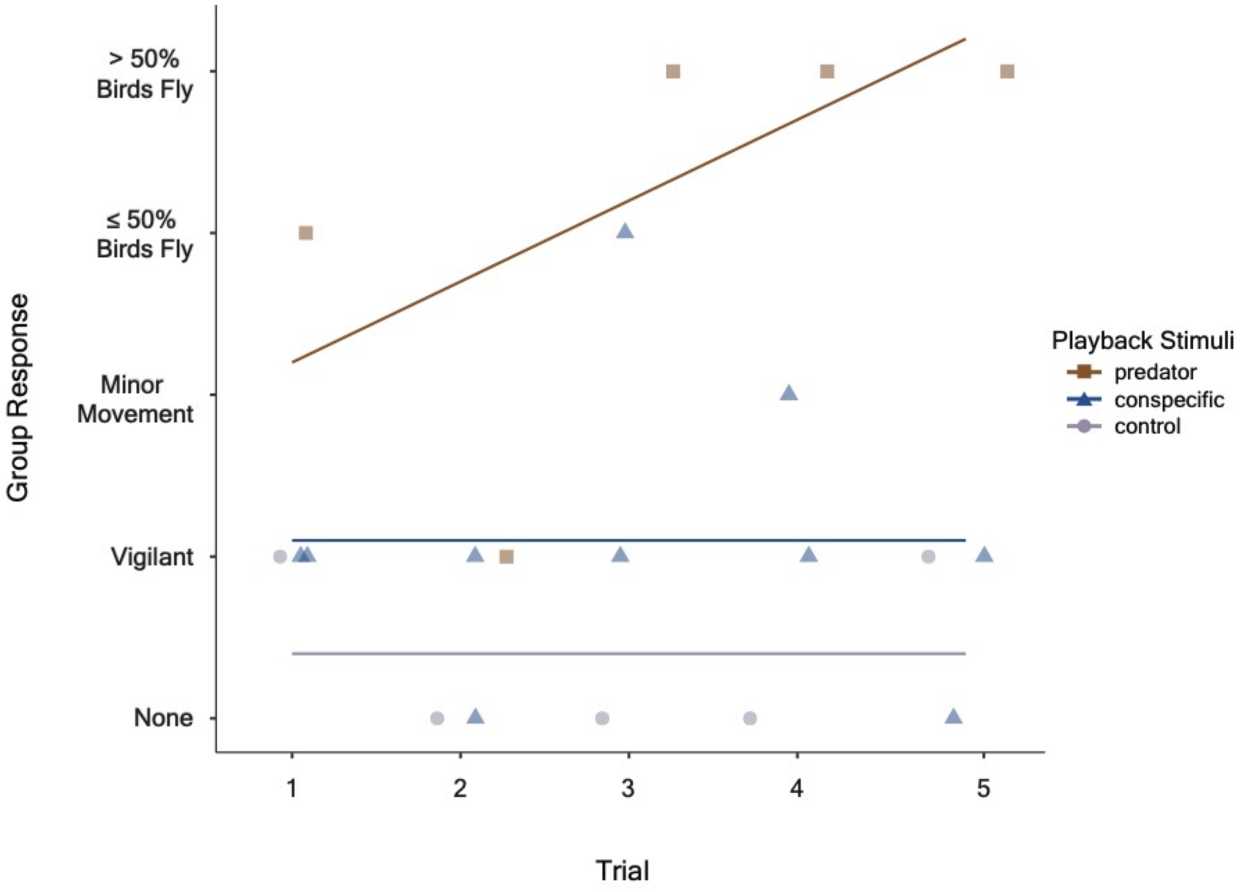
```
ordinal_1 <- clmm(group response ~ call category + (1|exemplar))
ordinal_2 <- clmm(group response ~ call category + trial + (1|exemplar))
ordinal_3 <- clmm(group response ~ trial + (1|exemplar))
ordinal_null <- clmm(group response ~ 1 + (1|exemplar))
```

Mixed-Model Equations for Latency:

```
LM_1 <- lmer(latency ~ call category + (1|exemplar))
LM_2 <- lmer(latency  ~ call category + trial + (1|exemplar))
LM_3 <- lmer(latency  ~ trial + (1|exemplar))
LM_null <- lmer(latency  ~ 1 + (1|exemplar))
```

Figure S3

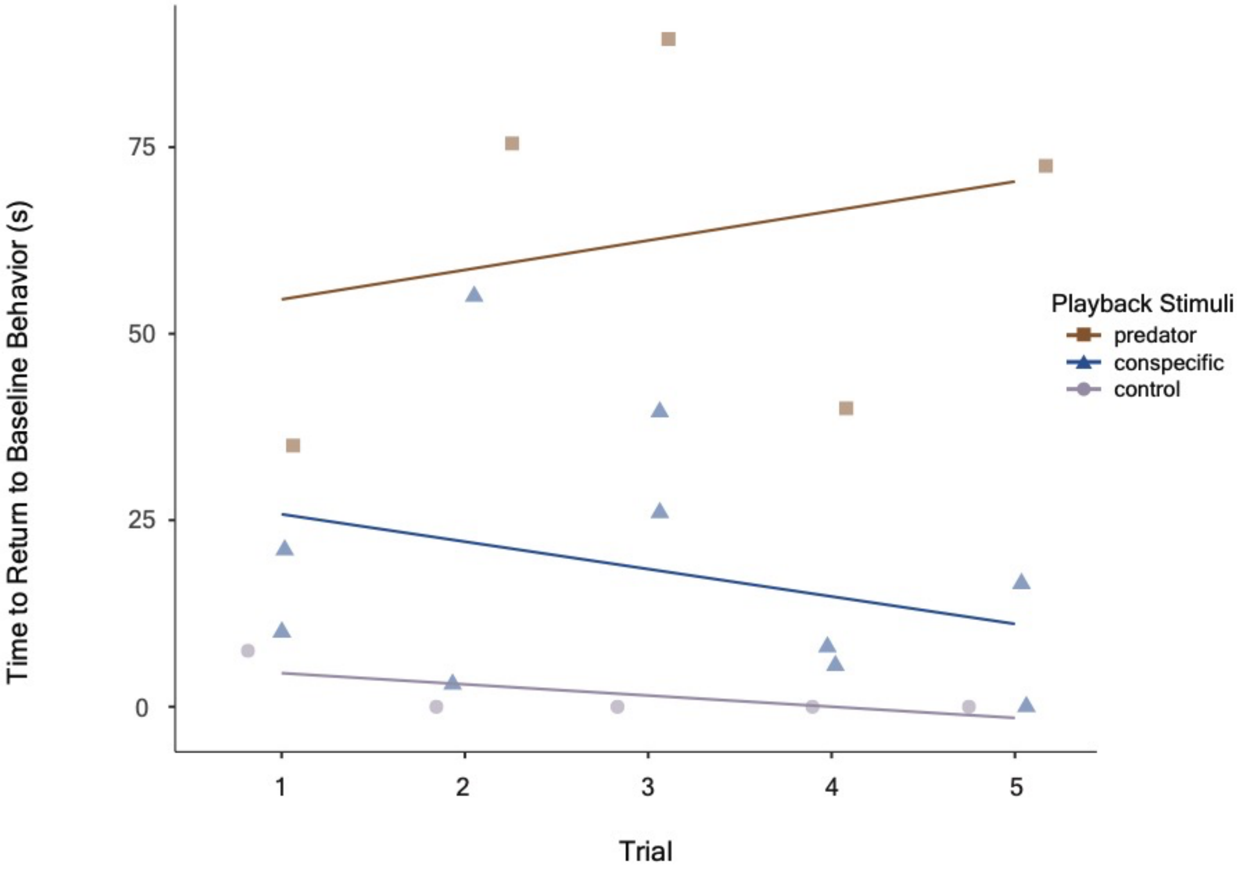
Group responses to playback stimuli over the test period.



Note. Group responses are colored by playback stimuli: predator playbacks (brown), conspecific playbacks (blue), and control playbacks (purple). Monk parakeets did not show habituation in their responses to playbacks over all trials.

Figure S4

Latency in response to playback stimuli over the test period.



Note. Latency is colored by playback stimuli: predator playbacks (brown), conspecific playbacks (blue), and control playbacks (purple). Monk parakeets did not show habituation in their latency to playbacks over all trials.

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