Effects of Traffic Noise on Foraging, Vigilance, and Aggression of the Zebra Finch (Taeniopygia guttata)

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Effects of Traffic Noise on
Foraging, Vigilance, and Aggression of the Zebra Finch (*Taeniopygia guttata*)

Sophia Palia

The College of William & Mary
Abstract

Noise pollution is an increasingly prevalent anthropogenic stressor that has detrimental effects on wildlife. Songbirds, in particular, are sensitive to noise pollution as they are inherently vocal animals. We know that noise affects how birds communicate and breed, but we know far less about how noise might influence patterns of foraging, vigilance, and aggression. These behaviors are important to understand because they can impact acquisition of resources, avoidance of predators, mating, breeding, and consequently overall fitness of birds. This experiment aims to help us better understand how noise pollution, specifically traffic noise, affects foraging, vigilance, and within-species aggression in a model songbird system, the zebra finch (Taeniopygia guttata). We found that exposure to traffic noise increased individual vigilance and decreased aggressive interactions in captive zebra finches, while it did not affect number of sentinels present (i.e. birds perched on rim of feeder exhibiting vigilant behavior). Additionally, there was no displacement away from noise or reduction in amount of food eaten in noisy conditions. These findings suggest that traffic noise causes vigilance to increase due to heightened perceived threat and aggression to decrease due to increased sociality and familiarity in zebra finches.
Effects of Traffic Noise on Foraging, Vigilance, and Aggression of the Zebra Finch (*Taeniopygia guttata*)

Noise pollution is becoming a widespread anthropogenic stressor due to the increase in industrialization, urbanization, and transportation needs of society. The addition of anthropogenic noise into an environment can significantly affect the well-being of wildlife (Kaseloo 2006). Noise pollution has been shown to damage hearing, mask sounds important to survival and reproduction, and introduce chronic stress which can result in physiological and behavioral changes in a range of species (Kaseloo 2006; Barber et al. 2010; Kight and Swaddle 2011; Purser and Radford 2011; Siemers and Schaub 2011; Blickley et al. 2012; Bunkley et al 2015; Kleist et al. 2018). Songbirds are particularly sensitive to noise pollution as they are inherently vocal animals. Anthropogenic noise has been shown to cause avoidance of noisy areas, changes in vocal communication, reproductive success, and mating preferences in songbirds (Rheindt 2003; Slabekoorn and Peet 2003; Patricelli and Blickley 2006; Swaddle and Page 2007; Francis et al. 2009). However, most of the studies examining noise pollution’s effect on songbirds focus on communication behaviors and mating, or the consequences of impaired communication.

It is important to understand other behaviors such as foraging, vigilance, and aggression as they play roles in acquisition of resources, predator avoidance, mating, and breeding in birds, all of which can impact overall survival and fitness of birds (Hinde 1970; Zann 1996). The effects of noise pollution on foraging, vigilance, and aggression in songbirds has not been studied greatly. Noise pollution has been shown to reduce foraging success in wildlife (Purser and Radford 2011; Siemers and Schaub 2011; Senzaki et al. 2016). It has been shown that birds avoid from noise and decrease foraging efficiency. For example, European starlings (*Sturnus vulgaris*) displaced away from a broadband (2-10kHz) loud noise resulting in decreased foraging at the noisiest sites.
(Mahjoub et al. 2015) and traffic noise reduced foraging efficiency in wild owls (Senzaki et al. 2016).

However, the effect of experimentally-presented traffic noise on foraging in songbirds has not been studied and is the focus of our first research question. Additionally, many studies have examined the energy trade-off between foraging and vigilance when exposed to introduced predatory threats. When exposed to predatory threats vigilance increases and consequently foraging decreases (Poysa 1987; Pascual and Senar 2013). Noise has been shown to increase time spent vigilant in chaffinches (*Fringilla coelebs*) when exposed to white noise (Quinn et al. 2006). However, vigilance has not been deeply examined when songbirds are exposed to isolated traffic noise. This question of how traffic noise affects vigilance in zebra finches is another focus of our study. We examine these behaviors in our research project as they can affect food acquisition and predator detection and thus the overall health and survivorship of songbirds.

Lastly, our third research question addresses whether or not traffic noise increases aggressive behavior from either impaired communication, increased stress, and/or increased density. Zebra finches are known to express aggressive behavior such as brawls and aggressive pecking (Evans 1970; Zann 1996). Aggressive behavior is important to zebra finches as it leads to establishment of dominance hierarchies which play a role in competition for mates, resources, and roosting sites (Zann 1996). Our question of how traffic noise affects aggression has important implications as an increase in aggressive behavior could affect the acquisition of resources, breeding, and fitness of noise-exposed birds (Hinde 1970).

In our experiment, we examined three research questions looking at how noise pollution, specifically traffic noise, affected three different behaviors in zebra finches: a) foraging, b) vigilance, and c) within-species aggression. Our first question examined how anthropogenic noise influences foraging, measured by the total amount of food eaten overall and the percent of food eaten at the noisy
feeder. We predicted that anthropogenic noise would decrease feeding efficiency because the zebra finches would spend more energy on being vigilant, be more stressed, and/or displace away from the noise and therefore eat less. During the noise treatment, we predicted the finches would exhibit more vigilant behavior and eat less because predator detection (vigilance) is compromised when foraging (Lima and Bednekoff 1999). To test this question, we recorded how much food was eaten at each of the two feeders. One feeder was in the room with the speakers playing traffic noise and one feeder was in a room further away from this noise source. This created a noise gradient between the two feeders. We were able to observe if birds displaced away from the noisier feeder by comparing the percent of food eaten in the noisy feeder out of total food eaten. We also measured total food eaten at both feeders to see if overall foraging behavior decreased during the noise treatment.

Our second research question examined how traffic noise affected antipredatory behavior, specifically vigilance. We predicted that vigilance would increase because traffic noise masks some communication in the finches. Therefore, we predicted that the birds would need to replace their impaired hearing with visual scanning and spend more time being vigilant. We recorded two metrics for vigilance: percent of time with head raised while eating (% heads up) and the number of birds exhibiting sentinel behavior (i.e. perched on rim of feeder with head raised looking out for predators while other birds fed). We used closed-circuit television (CCTV) security cameras to record these metrics at both of the feeders throughout each trial.

Our third question examined how anthropogenic noise influences aggressive behavior. We predicted that exposure to anthropogenic noise would increase aggressive behaviors because of impaired communication, increased stress, and/or increased density. We predicted that the zebra finches would resort to more physical and aggressive behaviors during the noise treatments because they would not be able to communicate as well vocally. Therefore, they would need to communicate physically. The birds could also experience increased aggression because they are under chronic stress which can lead to physiological and behavioral changes (Kight and Swaddle 2011; Kleist et al. 2018).
Aggression could also increase because of increased density from displacing away from the noise. To test this question of how traffic noise affected within-species aggression, we observed the finches for aggressive behaviors such as aggressive pecking, chasing, and displacement events.

Methods

Subjects, experimental housing, and noise treatments

We studied captive flocks of domesticated adult zebra finches in an outdoor aviary at the College of William & Mary (37.3°N, 76.7°W) from May to October 2017. Birds had ad libitum access to food (Volkman Super Finch Blend), cuttlebone, and water and were exposed to natural variation in photoperiod, temperature, and humidity.

The experimental aviary consisted of three connected free-flight outdoor cages or rooms (each approximately 2x2x2m) to comprise a three-room system in which we could present traffic noise at one end and record how this altered behaviors of the flocks of birds. We placed speakers, connected to an MP3 player, inside the two end rooms of the three-room system and insulated the walls between rooms with sound-absorbing foam (convoluted egg crate acoustic foam) to limit how noise spread between the rooms. In any experimental flock, traffic noise was played from one of these end-rooms and not the other. The two end-rooms (rooms 1 and 3) of the three-room system had a water dispenser and food dish in addition to perches and cuttlebones. Room 1 (R1) and room 3 (R3) were connected by a longer perch that extended through the middle room (room 2) and birds could move between the rooms through a 20 cm diameter hole in the walls between the rooms (Figure 1).

We started each 9-day trial by placing a randomly-selected flock of 12 birds (6 males, 6 females) in the three-room system for three days to acclimate and explore every room. No traffic
noise was broadcast during this acclimation period. All the birds were given uniquely-colored, temporary plastic leg bands so that we could identify individuals. Following the three days of acclimation, we then observed birds and collected data from each flock in three time blocks: three days of pre-noise treatment, three days of noise treatment, and three days of post-noise treatment. On each day, we observed the birds in the morning (09:00 to 10:45) and in the afternoon (12:00 to 13:45). In total, we conducted 9 sets of these trials (9 flocks of 12 birds each).

To create a noise treatment, we played a recording of traffic noise through speakers connected to an mp3 player (Mini Digital MP3 Player). The traffic noise ranged from 60dBA SPL to 85dBA SPL at any given moment, measured immediately outside of each cage using a calibrated sound meter (Digital Sound Meter Extech 407727). This recording was reflective of highway traffic, with quieter periods of a few small cars to louder periods of many large trucks. This traffic recording was looped to play continuously for three consecutive days. We switched the noise between R1 and R3 during the experiment every other flock so there was not a consistent side-bias in the study. We recorded sound pressure levels outside each room as we found that birds vocalized too much if we were inside the rooms and we wanted to minimize their influence on these assessments of amplitude. We recorded both the maximum and minimum dBA SPL reading over a 2 min period before the observation period and verified that the dBA SPL remained in this range throughout data collection.

**Behavioral observations of flocks**

During each observation period, we conducted one 8 min continuous focal observation of each of the 12 birds (starting with a bird selected at random and then in a randomized order) and recorded their behaviors according to an ethogram (Table 1) that we had designed from pilot observations. Other than behavioral categories, we also recorded who the focal bird was interacting
with (Table 2), its location in the cage system (Table 3), and the timing of the event. We recorded a new observation on every occasion that the focal individual either changed its behavior, altered who it was interacting with, and/or changed its location. We accounted for observer bias during pilot studies since we had three different observers. Each observer collected data at the same time from the same flock and we used an unpaired t-test to test for any extreme differences in each of our data.

Figure 1. Plan view of aviary. Think bars indicate wooden perches. The three cages were connected by one long perch. Shorter perches were placed at varying heights in rooms 1 (R1) and 3 (R3). F indicates food dishes, W indicates water, and S indicates speakers. Lines coming out of R1 speakers symbolize experimentally-introduced traffic noise.
<table>
<thead>
<tr>
<th>Abbr</th>
<th>Behavior</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>Displaced</td>
<td>The bird displaced another bird from a location</td>
</tr>
<tr>
<td>DB</td>
<td>Displaced by</td>
<td>The bird was displaced from a location by another bird</td>
</tr>
<tr>
<td>C1</td>
<td>Chasing (playful)</td>
<td>The bird is chasing/following another bird playfully (no attempt at physical contact/aggressive behavior/pecking)</td>
</tr>
<tr>
<td>C2</td>
<td>Chasing (aggressive)</td>
<td>The bird is chasing/following another bird aggressively (attempts at physical contact/aggressive behavior/pecking)</td>
</tr>
<tr>
<td>CB1</td>
<td>Chased by (playful)</td>
<td>The bird is being playfully chased/followed by another bird (no attempt at physical contact/aggressive behavior/pecking)</td>
</tr>
<tr>
<td>CB2</td>
<td>Chased by (aggressive)</td>
<td>The bird is being aggressively chased/followed by another bird (attempts at physical contact/aggressive behavior/pecking)</td>
</tr>
<tr>
<td>K</td>
<td>Pecking</td>
<td>The bird is pecking another bird</td>
</tr>
<tr>
<td>KB</td>
<td>Pecked by</td>
<td>The bird is being pecked by another bird</td>
</tr>
<tr>
<td>F</td>
<td>Feeding</td>
<td>The bird is eating seeds</td>
</tr>
<tr>
<td>M</td>
<td>Migrating</td>
<td>The bird moves between rooms. Be sure to note room #s</td>
</tr>
<tr>
<td>W</td>
<td>Drinking water</td>
<td>The bird is drinking water</td>
</tr>
<tr>
<td>P</td>
<td>Perched</td>
<td>The bird is perched (sitting on perch or wall)</td>
</tr>
<tr>
<td>G</td>
<td>Preening</td>
<td>The bird is grooming itself or another bird</td>
</tr>
<tr>
<td>N</td>
<td>Naptime</td>
<td>The bird is sleeping</td>
</tr>
<tr>
<td>CS</td>
<td>Courtship</td>
<td>Male attempts to mount female</td>
</tr>
<tr>
<td>S</td>
<td>Sex</td>
<td>The bird is mating</td>
</tr>
<tr>
<td>NS</td>
<td>Nesting</td>
<td>The bird is gathering supplies to add to nest or building nest</td>
</tr>
<tr>
<td>O</td>
<td>Other</td>
<td>The bird is doing a behavior not listed</td>
</tr>
</tbody>
</table>

Table 1. Ethogram of aggression and other behaviors. “Abbr” heading indicates abbreviated behavior used in data collection. Aggressive behaviors indicated in bold.
Table 2. Different color leg bands were attached to each of the 12 birds in each flock.

<table>
<thead>
<tr>
<th>IDs</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>RM</td>
<td>Red Male</td>
</tr>
<tr>
<td>PM</td>
<td>Pink Male</td>
</tr>
<tr>
<td>WM</td>
<td>White Male</td>
</tr>
<tr>
<td>YM</td>
<td>Yellow Male</td>
</tr>
<tr>
<td>GM</td>
<td>Green Male</td>
</tr>
<tr>
<td>OM</td>
<td>Orange Male</td>
</tr>
<tr>
<td>PF</td>
<td>Pink Female</td>
</tr>
<tr>
<td>WF</td>
<td>White Female</td>
</tr>
<tr>
<td>YF</td>
<td>Yellow Female</td>
</tr>
<tr>
<td>KF</td>
<td>Black Female</td>
</tr>
<tr>
<td>BF</td>
<td>Blue Female</td>
</tr>
<tr>
<td>OF</td>
<td>Orange Female</td>
</tr>
</tbody>
</table>

Table 3. Possible locations of birds in the three-room system at any given time.

<table>
<thead>
<tr>
<th>Abbr</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>HP</td>
<td>High perch (low 4 perches in R1 &amp; R3, long continuous perch in R1, R2, R3)</td>
</tr>
<tr>
<td>F</td>
<td>Feeder</td>
</tr>
<tr>
<td>WL</td>
<td>Wall</td>
</tr>
<tr>
<td>FL</td>
<td>Floor</td>
</tr>
<tr>
<td>B</td>
<td>Cuttlebone</td>
</tr>
<tr>
<td>FM</td>
<td>Foam</td>
</tr>
<tr>
<td>W</td>
<td>Water dish</td>
</tr>
<tr>
<td>O</td>
<td>Other</td>
</tr>
</tbody>
</table>
Foraging

In order to quantify the impact of traffic noise on foraging, we weighed the amount of food eaten (g) (to 0.1g precision on an electronic balance) at the two feeders during two days of each 3-day noise treatment. Before the morning observation period (08:40-09:00), we removed food dishes and trays from both rooms and weighed the amount of uneaten food. We then removed feces to minimize additional weight that could affect our estimation of food consumed. After the data were recorded, we disposed of any uneaten food and refilled food dishes to the baseline amount of 120g of millet. Very little food was spilled onto the aviary floor as all feeding cups were placed in a much larger (60cm) plastic tray that caught the vast majority of spilled seed and empty husks.

To calculate total food eaten, we subtracted the weight of the remaining food from the original 120g to calculate food consumed every day of the 9-day trial in both of the feeders. We then took the sum of these measurements to calculate the total food eaten at both feeders every day. We calculated the average total food eaten for pre-, during-, and post-noise treatments. To calculate “% of food eaten on noisy side,” we took the food eaten at the feeder closest to the noise and divided it by the total food eaten at both feeders. We then calculated the average percent of food eaten on the noisy side for pre-, during-, and post-noise treatments.

Vigilance

To test how traffic noise influenced vigilance behaviors, we recorded birds at each of the two feeders with a CCTV camera (LOREX 1080p PoE Network Bullet Camera). During the 9 days of each trial, we recorded 30 min during the morning observation period (09:00-09:30) and 30 min during the afternoon observation period (12:30-13:00) at both feeders. These specific times of our observation periods were selected because more birds were at the feeders at these
times based on pilot data. At the start of every feeding bout (when at least one bird came to the feeder), the number of birds present, number of individuals with their heads up, number of individuals with their heads down, and number of sentinels present were recorded. An individual was defined as a sentinel if it perched on the outer rim of the feeder while other birds fed. These individuals adopted prominent, exposed positions where they displayed constantly vigilant behavior while others foraged, characteristic of sentinel behavior (Hollén et al. 2008; Ridley et al. 2010). We used a cross-sectional approach and sampled for vigilance behaviors every 30 s until the end of the bout. Number of bouts per 30 min observation period ranged from 0-7 and number of observations ranged from 0-57. In order for an observation period to be included in our analyses, there needed to be at least 4 observations of feeding in at least 1 bout.

To calculate our metric for individual vigilance, “% head up,” we took the sum of birds with their heads up and heads down during each 30s observation at both feeders. We then divided the number of birds with their heads up by the total sum to calculate “% head up” for each 30s observation. We found the average “% head up” for every 3-day noise treatment in each flock. To calculate our metric for group vigilance, “# of sentinels,” we found the average number of sentinels in each observation period at both feeders and then took the average for every 3-day noise treatment in each flock.

**Aggression**

To measure aggression, we recorded pecking events, chasing events, and displacements during the morning and afternoon observation periods each day (Table 1). As stated previously, each individual was followed for 8 min and all their aggressive interactions with other individuals were recorded. Since there tended to be a varying number of total interactions during noise and across flocks, we took the percentage of total interactions that were aggressive. In
doing so, aggression was not dependent on the total number of interactions. To calculate our metric “% of interactions aggressive,” we took the sum of aggressive interactions (pecking, chasing, displacement events) and divided it by the total number of interactions.

**Statistical Analysis**

To examine if birds were displaced away from the source of traffic noise, we performed a paired *t*-test to compare the percent of food eaten at the noisier feeder compared to the quieter feeder during pre-noise and noise treatments. To test whether amount of food consumed was affected by the introduction of traffic noise, we performed a paired *t*-test to compare total food eaten in pre-noise and noise treatments. To examine how the amplitude of noise influenced the percentage of interactions that were aggressive we performed a repeated-measures ANOVA where stage of the noise treatment (pre-noise, during-noise, post-noise) was the within-subject factor. We also performed a priori contrasts of pre- vs during-noise and during- vs post-noise to further examine the changes in vigilance through the experiment. To test whether the two metrics of vigilance (% heads up, sentinelling) were affected by noise we performed repeated-measures ANOVAs where stage of the noise treatment (pre-noise, during-noise, post-noise) was the within-subject factor and group size was a covariate. We also performed a priori contrasts of pre- vs during-noise and during- vs post-noise to further examine the changes in vigilance through the experiment. Test significance was set at *p*=0.05 and if not stated otherwise, we report means ±SE.
Table 4. Sound pressure level, dBA SPL, during the treatments experienced by each flock of experimental birds. The top number is the average dB SPL during the 3-day treatment and below is the dBA SPL range recorded during that same period. X’s mark the flocks that were used in each of our studies. F indicates feeding study, V indicates vigilance study, and A indicates aggression study. dBA SPL grand mean for each noise treatment across all flocks indicated in bold at the bottom.
Results

Foraging

Figure 2. Mean (±SEM) percent of food eaten in room with speakers playing traffic noise during pre-, during-, and post-noise treatments. There was no significant difference in percentage of food consumed on noisy side between the three treatments indicating birds were not displacing away from introduced traffic noise.

There was no statistically significant effect of traffic noise on percent of food eaten in room with speakers playing traffic noise ($t$ = -1.30, $df$ = 7, $p$ = 0.2352; Figure 2). Although “% of food eaten on noisy side” did increase with noise, the standard error around this average was large and overlapped with 50%—which indicates equal consumption on the noisier compared with the quieter side of the aviary. This indicates that birds did not displace away from the noise which is consistent with our observational data (C. Hawkins, unpublished data).
There was no statistically significant effect of traffic noise on total food consumed ($t = -1.0299$, $df = 7$, $p = 0.3373$; Figure 3). Consumption of food remained consistent throughout pre-, during-, and post-noise treatments.

Figure 3. Mean (±SEM) total food eaten in R1 and R3 feeders during pre-, during-, and post-noise treatments. Each bar is an average of daily food consumed in each noise treatment over 8 flocks.
Figure 4. Average percent of observations with birds in the head-up position (vigilant) vs head-down position (feeding) during pre-, during-, and post-noise treatments. Tendency for “% heads up” to increase with noise. F1-5 indicate responses of the five different flocks (indicated by V on Table 4).
There was no statistically significant effect of noise on “% heads up” while adjusting for variation in group size ($F_{2,10} = 2.11$, $P = 0.172$). However, there was a tendency for this metric of vigilance to increase within flocks with noise (pre- vs during-noise contrast, $F_{1,5} = 5.33$, $P = 0.069$) and then remain the same after the noise treatment finished (during- vs post-noise contrast, $F_{1,5} = 0.002$, $P = 0.965$; Figure 4). There was no indication that noise affected the number of sentinels observed at the feeders ($F_{1,5} = 0.353$, $P = 0.711$), with neither contrast effect approaching statistical significance (pre- vs during-noise contrast, $F_{1,5} = 0.209$, $P = 0.666$) during- vs post-noise contrast, $F_{1,5} = 0.123$, $P = 0.740$; Figure 5).

Figure 5. Average number of birds displaying sentinel behavior throughout pre-, during-, and post-noise treatments. No consistent change in average number of sentinels between treatments F1-5 indicate responses of the five different flocks of birds (indicated by V on Table 4).
Aggression

Figure 6. Effects of traffic noise on percent of all interactions observed that were aggressive during pre-, during-, and post-noise treatments.

Noise amplitude somewhat affected the % of aggressive interactions ($F_{2,16} = 2.45$, $P = 0.118$) with aggression reducing as the traffic noise is introduced (pre- vs during-noise contrast, $F_{1,8} = 4.76$, $P = 0.061$) but then not altering as the noise is turned off (during- vs post-noise contrast, $F_{1,8} = 0.077$, $P = 0.788$; Figure 6).
Discussion

Our results indicate that there are trends for individual vigilance to increase and aggressive interactions to decrease in zebra finches with exposure to traffic noise in an outdoor aviary over a 3-day period. Our vigilance findings are generally consistent with our hypothesis that vigilance would increase with traffic noise due to impaired communication and/or stress. In our study, we found that there was a tendency for birds to increase vigilant behavior (% heads up) at feeders when traffic noise was introduced. While this trend was not quite statistically significant, the sampling error was large as we had a sample size of only five. There was no indication that number of birds observed engaging in sentinel behavior differed between noise treatments. Taken together, our two forms of data indicate that traffic noise increases individual vigilance (% heads up) and does not change group vigilance (sentinelling).

Increased vigilance in response to traffic noise could impact other mutually exclusive behaviors, such as foraging. When exposed to predatory threats, vigilance increases and thus foraging decreases (Poysa 1987b; Pascual and Senar 2013). The trade-off between foraging and vigilance has been studied in a variety of species (Bachman 1993; Fortin et al. 2004). Others have reported a trade-off between foraging and vigilance in response to noise pollution. Pronghorn (*Antilocapra americana*) were found to spend more time vigilant and less time foraging within 300 meters of a road (Gavin and Komers 2006). In response to playback of predator-elicited alarm calls, adult California ground squirrels (*Spermophilus beecheyi*) increased vigilance behavior more at a site heavily impacted by loud wind turbines than in a quiet control site (Rabin et al. 2006). White noise has been shown to increase time spent vigilant and decrease foraging in chaffinches (*Fringilla coelebs*) (Quinn et al. 2006). However, our study is the first to document how experimentally-presented traffic noise affects vigilance response in birds.
While we did not observe a decrease in amount of food eaten during noise treatments in our study, increased vigilance has the potential to decrease foraging efficiency. Additionally, it has the potential to decrease reproduction and fitness as increased vigilance is an indicator for increased stress (Clinchy et al. 2004, Blickley et al. 2012). Therefore, our findings that individual zebra finches increased vigilance when exposed to traffic noise could mean a reduction in foraging efficiency, reproduction, and fitness in wild songbird populations exposed to traffic noise.

One reason why vigilance did not increase as much as expected could be an artifact of reduced perception of predatory risk of captive birds. These birds could be desensitized and have a reduced perception of risk of predators since they were raised in captivity and have experienced no actual depredation. However, they still have an innate anti-predator response of increasing vigilance, evident in our vigilance results and other studies (Goth 2001; Caro 2005). Similarly, it is important to note that these birds have been raised in the aviary in fairly noisy conditions for multiple generations. While the ambient noise in the aviary was not as extreme as the traffic noise played during noise treatments, it still could have had an effect on the response of birds to the traffic noise. The birds could be more acclimated to the noise as they were exposed to it while growing up. It would be an interesting area of future research to see how exposure of birds to noise pollution as juveniles affects response to noise in adults.

Our findings that aggressive interactions tended to decrease with traffic noise were unexpected. We hypothesized that aggression would increase with noise due to impaired vocal communication, increased stress and/or increased density. However, we actually found the exact opposite response of birds to the noise: aggressive interactions decreased with noise. Due to the lack of displacement of birds away from the noisy room, there was no increase in bird density.
Therefore, we did not expect aggression to increase because of increased closeness. However, we did expect aggression to increase due to impaired acoustic communication abilities and stress. As mentioned previously, this could be due to the fact that these birds were raised in noisy conditions.

However, this decrease in aggressive behavior could be related to the increased sociality of the flocks during noise treatments (C. Hawkins, unpublished data). Traffic noise has been shown to increase sociality and thus familiarity in zebra finches when exposed to traffic noise (Hawkins 2018, unpublished). Aggression is lower in individuals that frequently interact than in individuals that rarely interact (Jaeger 1981). This phenomenon that more familiarity leads to a reduction in aggression has been found in eels and could explain our findings with zebra finches (Ward and Hart 2003). Within a species, more aggressive individuals may outcompete less aggressive individuals for resources (Duckworth 2008). However, aggression can be costly, sometimes resulting in reduced survivorship and fitness (Marler and Moore 1988; Duckworth 2006). While a reduction in aggressive behavior could be detrimental to zebra finches as it is important in competition for mates and roosting sites (Zann 1996), if all birds experience a decrease in aggression due to increased familiarity it may not prove to be unfavorable. In fact, decreased energy spent on aggression could be somewhat beneficial (Cain and Ketterson 2013).

Traffic noise has been shown to disperse and decrease sociality in wild red-backed fairywrens, therefore aggression might increase with noise in non-captive songbirds (C Hawkins, unpublished data). Field studies should be conducted to examine if aggression still decreases in songbirds in non-captive conditions.

We could test this question by observing aggressive interactions in wild populations of songbirds in response to experimentally presenting traffic noise through speakers. We could use
a similar design to our captive experiment with periods of pre-, during-, and post-noise. We could identify aggressive interactions (pecking, chasing, displacement events) using binoculars. This experiment should be conducted during the breeding season when aggression and territorial behavior is more common (Zann 1996).

Our foraging results were not consistent with our hypothesis that traffic noise would decrease food consumed due to increased vigilance and/or displacement away from the noise. We found that there was no consistent decrease in percent of food eaten on the noisy end or in total food eaten. This result is unexpected since it has been shown that foraging decreases with noise (Purser and Radford 2011; Siemers and Schaub 2011; Senzaki et al. 2016). Studies show that traffic noise can cause displacement away from noise and a reduction in foraging efficiency in birds (Mahjoub et al. 2015; Senzaki et al. 2016). Our results are interesting because there was a tendency for individual vigilance to increase with traffic noise. The slight increase in vigilance during noise was not enough to displace birds or to disrupt the amount of food consumed. This could be due to the fact that these birds were raised in noisy conditions over multiple generations. Additionally, this lack of change in total food eaten could be explained because noise pollution is a physiological stressor resulting in increased stress hormone levels (Wasser et al. 1997; Creel et al. 2002; Chandralekha et al. 2005; Hayward and Wasser 2006; Crino et al. 2011). Studies show that increased stress levels increase metabolism and energy-use and can actually lead to an increase in foraging (Ames 1978; Wendelaar-Bonga 1997; Wale 2013). As we did see a trend for vigilance to increase with noise in our experiment, we know that the birds experienced some levels of increased stress. The birds could have been eating more during noise to make up for energy used to increased their metabolism.
However, increased vigilance has the potential to decrease foraging efficiency and thus reduce health and survival of the zebra finches. This vigilance study could be conducted again with a larger sample size to reduce sample error. Additionally, experiments examining impact of traffic noise on foraging, vigilance, and aggression in wild songbirds would be useful in better understanding our questions. Another interesting behavior to examine in response to traffic noise would be dominance since we saw such interesting impacts on aggression. Taken together, our results suggest that traffic noise increases individual vigilance due to increased perceived threat and decreases aggression in zebra finches due to increased familiarity. While we did not observe a reduction in foraging in noisy conditions, an increase in vigilance with traffic noise has the potential to decrease foraging efficiency. It is important to understand and quantify the effect traffic noise has on songbirds and other wildlife as it can lead to conservation efforts and policy changes to help reduce traffic noise in affected habitats.
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References


