

**The effect of call similarity on call discrimination by Tree Swallow
(*Tachycineta bicolor*) nestlings in the presence of noise**

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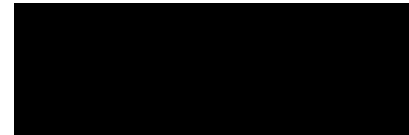
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Abstract

As the extent of noise expands with urbanization, so does the extent of its impacts on wildlife. The impact of noise is particularly strong when it comes to the disruption of avian communication. Birds rely heavily on acoustic communication. They are especially vulnerable during the nestling stage of their lives because of their heavy reliance on parental care for survival. It is assumed that in noisy environments call recognition becomes difficult and thus would make already difficult distinctions (i.e., similar calls) more difficult, however this assumption is yet to be tested. My study attempts to answer the question: How does call similarity impact the call discrimination of nestling Tree Swallows (*Tachycineta bicolor*) in the presence of noise? A study in 2016 investigated the impacts of noise on call recognition by raising half of the nests in noise while the other half were used as a control group. Both groups were then administered two sets of playback tests, one under noisy conditions and one under quiet conditions. During each test, a parental call was played as well as the call of an unfamiliar adult and the nestlings' responses were recorded. Using data collected in 2016 my study calculated the spectrogram correlation and Euclidean distance of 37 call pairings (one parent call and one unfamiliar adult). The impact of rearing treatment (quiet vs. noise), playback condition (quiet vs. noise) and call similarity measures were then compared to the nestling response data using a mixed linear model. Neither call similarity nor noise had a significant impact on the nestlings' call discrimination, suggesting that even when calls are similar and conditions noisy, nestlings can access the call elements necessary for recognition. While this study found no impact of noise on call recognition, noise cannot be ignored especially given its other, more detrimental impacts (e.g., cochlea damage). Further research into the exact mechanism used by nestlings and the impacts of inconsistent noise (e.g., noise which occurs at fluctuating amplitudes) is needed to better understand how nestlings discriminate between similar calls in noisy environments.

1.0 Introduction

As cities have grown and wild spaces have been developed, anthropogenic noise, such as from cities and roads, has become more prevalent around the world (Rosa & Koper, 2018). Such noise often has a higher amplitude and is more persistent than the sounds in less disturbed soundscapes (Barber et al., 2010; Rosa & Koper, 2018). Cities like New York can have an average noise level over 70 dBA, which can be detrimental for both humans and wildlife by contributing to chronic hypertension and disrupting communication (Barber et al., 2010; McAlexander et al., 2015). Animals that rely heavily on sound to communicate and forage, such as whales, bats and birds, may be especially negatively affected by any disruptions noise makes to communication (Erbe et al., 2016; Rosa & Koper, 2018; Schaub et al., 2008).

Acoustic communication plays an especially important role in the raising of young and the presence of noise can disrupt communication between parents and their offspring, increasing predation risk and decreasing feeding rates (Leonard et al., 2015). This study will examine how anthropogenic noise affects parent-offspring communication, specifically how the presence of noise influences the role of call similarity on the ability of Tree Swallow (*Tachycineta bicolor*) nestlings to differentiate between their parents and other adults.

1.1 Background and Context

Noise can impact animals in a number of ways. Impacts can be behavioural, such as causing the avoidance of noisy areas, or physiological, such as causing an increase in chronic stress hormones (Barber et al., 2010). One particularly important impact is the disruption of communication between individuals or groups. The most direct impact on communication occurs when the frequency of the noise overlaps with the signal frequency or when its amplitude (volume) overpowers that of the signal, a phenomenon referred to as “energetic masking”. Noise can also distract the recipients of signals causing them to miss important cues or even the entire signal, a phenomenon called “informational masking” (Kidd et al., 2008, Rosa & Koper, 2018). In addition to these impacts, noise can amplify the negative effects of other human-caused impacts such as habitat loss and fragmentation (Barber et al., 2010).

There are adjustments animals can make to avoid the disruptions in communication caused by noise. Such changes include signalling at different times, increasing call amplitude (volume) or changing the frequency of their calls (Horn et al., 2020). For example, Tree Swallow nestlings develop higher frequency calls with simpler structures

when raised in noisy environments (Leonard & Horn, 2008). Bats have also been observed to avoid hunting in areas where noise occurs within a certain frequency range because it hinders their ability to locate their prey (Schaub et al., 2008). As noise continues to alter natural soundscapes, however, these adjustments may lose their effectiveness (Horn et al., 2020).

The nature of anthropogenic noise can make it difficult for animals to alter their communication strategies. In 14 National Parks in the United States, for example, anthropogenic noise was observed more than 25% of the time between 7am and 10pm. At some of the sites, anthropogenic noise could be heard over 50% of the time (Barber et al., 2010). The amplitude of human-caused noise can range from 60 dB (a normal conversation) to 140 dB (a siren at 100 feet) and can occur at many different frequencies (Healthwise, 2019). With anthropogenic noise occurring for most of the day, and across many amplitudes and frequencies, signalling at different times, amplitudes or frequencies may not be possible.

Birds are often used to study the effect of noise on wildlife because of their complex acoustic communication, as well as their strong reliance on such communication (Rosa & Koper, 2018). Birds rely on auditory communication for a wide range of functions, from alerting each other to the presence of predators to attracting mates. Using specific cues, bird can differentiate between different calls and respond accordingly (Jouventin et al., 1999). For example, Superb Fairy-wrens (*Malurus cyaneus*) use peak frequency and the number of frequency cycles to assess the threat level of a predator and to determine the appropriate response (i.e., whether or not to take cover and how long to remain in cover; Fallow et al., 2011). Despite ample demonstrations that noise disrupts communication, however, it is unclear how noise disrupts these cues.

One way to examine how noise disrupts the use of call recognition cues is to test how individuals recognize calls of known individuals in noise. Call recognition cues are particularly important during the nesting period. One way to examine how noise disrupts the use of call recognition cues is to test how individuals recognize calls of known individuals in noise. Call recognition cues are particularly important during the nesting period. During this time, nestlings respond to their parents calls by begging to signal their hunger. At the same time, the parent relies on those begging calls to determine the rate at which they need to deliver food (Leonard & Horn, 2008, Corney & Barber, 2018). For parents, particularly those which live in dense colonies, failing to identify their nestling could result in the provision of care to a nestling that is not their own, taking resources away from their own nestling. For nestlings, mistaking another

adult for their parent could mean extra food but it could also draw predators' attention to their location or result in an attack from an unrelated adult (Reers et al., 2013). Should noise mask or inhibit birds' ability to differentiate between calls, the number of mistakes being made could increase along with the risk associated with them.

1.2 Summary of Literature

What enables individuals to make distinctions between calls, and what inhibits this ability, is not entirely understood. Call similarity is believed to be one factor that plays a role in why birds fail to distinguish between individuals. Specifically, in Zebra Finch (*Taeniopygia guttata*) nestlings, the response is stronger when calls are more similar to those of parents than when calls are dissimilar (Reers et al., 2013). Similarly, Superb Fairy-Wrens respond to the alarm calls of other species when these calls are similar to their own with the intensity of the response increasing with similarity (Fallow et al., 2011). Both studies looked solely at call similarity, but did not incorporate other environmental factors which may influence the ability of birds to distinguish between calls.

Noise may cause birds to mistake one individual for another. A study published in 2020 offers a unique chance to examine how this might happen. The study tested the effect of noise on the ability of Tree Swallow nestlings to differentiate between their parents and other adults. The study introduced half of the nestlings to noise during their development while the other half was raised in naturally occurring, ambient noise (Horn et al., 2020). Once the noise was removed, each nest was given four randomly ordered playback tests: both a parent call and another adult's call were played back to the nestlings, once with noise and once without. Each nest was given a begging score based on a one to five scale of intensity and the duration of nestling calling was recorded.

While noise did reduce begging intensity, overall nestlings could differentiate between the two calls regardless of how they were raised or which test they received. This suggests that overall response and the ability to discriminate between calls are processed differently (Horn et al., 2020). While most nestlings succeeded in identifying the correct call, this was not the case for all nestlings. This study did not identify why such mistakes occurred, nor did it look into the exact mechanisms the nestlings used when discriminating between calls. This study will add to the body of literature that examines how call similarity and noise both impact call discrimination

by investigating how these two factors influence a nestling's response when they are observed together.

1.3 Study Introduction and Summary of Approach

The objective of the study was to better understand the effect of noise on nestling-parent communication, specifically to expand on the results of Horn et al.'s (2020) study along with observation that an increase in call similarity results in an increase in recognition errors (Reers et al., 2013) to better understand how nestlings differentiate between calls in the presence of noise. The similarity of the call pairs in Horn et al.'s (2020) study was analyzed with the nestling response data in order to better understand the effect of noise on the ability of nestlings to differentiate between their parents and other adults. The experiment was conducted at one study site and in one year, however as it addressed fundamental mechanisms of behaviours, it was hoped its spatial and temporal constraints would not compromise the generalizability of the results.

The research question for this study was:

- 1) How does call similarity affect the discrimination between parents and other adults by nestling Tree Swallows in the presence of noise?

In other words, this study sought to determine if Tree Swallows have greater difficulty distinguishing between similar calls in the presence of noise. It was predicted that if the parent call was acoustically similar to the call of the other adult, the nestling would fail to differentiate between the two, and that the presence of noise would amplify this effect. The call similarity of the pairs used during Horn et al.'s (2020) playback tests was tested using the sound analysis software Raven Pro 1.6 (Center for Conservation Bioacoustics, 2019). The nestlings' responses were then correlated with those similarity measures. The results of this study provided more insight into the impacts of noise on wildlife, how human noise may be affecting already vulnerable species and could be used to inform future policies and decisions surrounding urban development and noise restrictions.

2.0 Literature Review

Much research has been conducted on the effect of noise on animal communication, particularly avian communication, but the impact of noise on parent-offspring communication and call discrimination is under-represented. Even fewer studies have explored the role call similarity plays in call discrimination, especially in the presence of noise. In this review, research regarding the effect of noise on communication and call discrimination, especially during parent-offspring communication, will be highlighted. Attention will be drawn to knowledge gaps in the research looking at call differentiation in the presence of noise, with a specific focus on how call similarity effects this discrimination.

2.1 The Nature of Noise

Human-caused noise, such as the noise produced by roads and aircraft, often occurs at a higher amplitude, lower frequency and over a more extended period of time, than other noise (Dowling et al., 2012; Potvin, 2017). As urban centres expand and populations grow, human-induced changes to the soundscape have increased the number of high-intensity noise events and have increased the amplitude of background noise overall (Shannon et al., 2016). As anthropogenic noise is occurring at an increasing rate, it is becoming more prevalent and the extent of its impact on wildlife and the environment is increasing. Noise, even at low amplitudes, can elicit behavioral or physiological responses in wildlife (Shannon et al., 2016). Behavioural responses include avoiding areas, changing song structure and changing predator-prey dynamics. In the presence of noise levels as low as 42 dB, the population densities of woodland songbirds have been observed to decline, suggesting that birds avoid areas where noise is present (Forman & Alexander, 1998). Birds also shift the frequency ranges or amplitude of their songs as a response to noise (Hage et al., 2013; Pohl et al., 2012; Seger-Fullam et al., 2011). Noise can also cause changes in predator-prey dynamics and foraging efficiency, especially in the case of auditory predators (Mason et al., 2016; Siemers & Schaub, 2011). Physiologically, noise can induce a change in the stress response such as elevated stress hormones and can affect overall health, such as causing chronic hypertension (Barber et al., 2010; Crino et al., 2013). Given noise's ability to impact wildlife in a wide variety of ways, there are many impacts that are still not fully understood.

Understanding the impacts of noise is important because it can identify potential threats to conservation as noise becomes more prevalent. Noise can threaten species by pushing them

out of otherwise suitable habitat, as wildlife tends to avoid noisy areas (Francis et al., 2009). It is a particular threat to species that are unable to adapt to its impacts and can decrease the species richness and diversity of an area, because only species which can adapt successfully to noise can remain (Francis et al., 2009; Swaddle et al., 2015). Noise can also exacerbate the pre-existing threats and dangers wildlife face such as habitat fragmentation (Barber et al., 2010; Dowling et al., 2012). While there is a growing body of evidence that points to the negative impacts of noise, these impacts are often not included in conservation and restoration efforts (Swaddle et al., 2015). To fully address the concerns surrounding noise and its threats to conservation, the potential impacts of this increasingly present phenomenon must be understood.

2.2 The Effect of Noise on Communication

Noise primarily affects the ability of the receiver to intercept and understand signals, in turn changing their response. In the presence of noise, the distance at which the signal can be detected and understood, its “active space”, is reduced (Rosa & Koper, 2018). Noise can also mask the signal, causing the receiver to miss parts of or the entire call. Thus, receivers are less likely to respond to calls and signals in the presence of noise (Grade & Seiving, 2016). Noise also increases the probability that the receiver will respond inappropriately, which could result in lost opportunities (e.g. failing to identify a potential mate) or predation (Rosa & Koper, 2018). In some cases, an increase in noise level caused an increase in the use of other sensory channels. Using channels such as visual stimuli may help animals communicate despite the noise. Nonetheless, in cases where multi-modal communication is necessary for the effective communication of the entire signal, noise will still impact the signal’s reception (Halfwerk & Slabbekoorn, 2015.; Leonard et al., 2015; Rosa & Koper, 2018). Noise can affect communication in several ways, with the most prominent being masking the signal before it can be received and processed.

2.2.1 Masking

Signal masking is believed to be the primary mechanism by which noise disrupts communication. Masking appears to be a critical mechanism in lowering the response to calls (Grabarczk & Gill, 2020; Pohl et al., 2009; Rosa & Koper, 2018; Zhou et al., 2019). It occurs primarily in two ways: energetic masking and informational masking (Rosa & Koper, 2018). Both the amplitude and frequency range of anthropogenic noise heavily influence the degree to which a signal is masked (Pohl et al., 2009). For example, signal masking as a result of

anthropogenic noise affects low-frequency calls to greater degree than high-frequency calls, suggesting that masking impacts certain types of signals and their receivers more than others (Francis et al., 2011; Rosa & Koper, 2018; Zhou et al., 2019).

2.2.2 *Energetic Masking*

Energetic masking occurs when the amplitude and frequency of the noise overlap with that of the signal frequency (Rosa & Koper, 2018). Energetic masking has been observed to disrupt the acoustic communication of marine mammals, such as dolphins and whales (Erbe et al., 2016; Founda et al., 2018), and of terrestrial taxa that rely heavily on acoustic communication, such as birds, bats and frogs (Grabarczk & Gill, 2020; Hage et al., 2013; Rosa & Koper, 2018; Shannon et al., 2016; Zhou et al., 2019). Having been observed across several taxa and ecosystems, it is believed that energetic masking is the most prevalent type of masking.

Energetic masking can increase the detection threshold by 25dB or more, increasing the signal amplitude necessary for detection, thus drastically altering the distance at which the signal can be detected and processed (Lohr et al., 2003; Rosa & Koper, 2018). Another way in which energetic masking affects detection distance is by degrading the signal faster than it would in a quiet environment. While the structure of a signals does naturally start to change as it moves away from the source, energetic masking can make the effects of such degradation worse (Grabarczk & Gill, 2020). By reducing the active space of signals and amplifying the effects of degradation, energetic masking decreases the likelihood of effective communication between individuals.

Anthropogenic noise often occupies low frequency ranges, making it more likely that it will mask the signals of species whose calls occur at lower frequencies (Dowling et al., 2012; Francis et al., 2011; Rheindt, 2003). In a study looking at three species of grassland birds, Rosa & Koper (2018) found that species with lower peak frequencies experience more energetic masking than those with high peak frequencies. Species whose calls occupy low frequency ranges not only call less in areas closer to roads but are also present in lower densities compared to areas where noise from roads cannot be heard, suggesting that they avoid noisy areas (Rheindt, 2003). While it is relatively clear why species with low frequency calls respond negatively to noise, it is less clear why species with high frequency calls are sometimes found in greater abundance in noisy areas, suggesting a positive response to noise (Francis et al., 2011). It is likely that this response is not only related to the species' ability to call in noise but to benefits

such as reduced predation and decreased competition in noisy environments (Francis et al., 2011). Although it is not entirely understood why some species respond positively to noise, it is largely accepted that species with low frequency calls experience more energetic masking as a result of anthropogenic noise (Dowling et al., 2012; Francis et al., 2011; Rheindt, 2003; Rosa & Koper, 2018).

As the entire signal is not always disrupted, energetic masking can affect signal detection to varying degrees. For signals that convey multiple messages at once, partial masking may mean that only parts of the message are effectively communicated while the other parts are lost (Johnstone, 1996; Rosa & Koper, 2018). Signals that convey redundant information (i.e. the same information more than once), may be more resistant towards partial masking and may still effectively communicate the information to the receiver even when energetic masking occurs (Johnstone, 1996; Rosa & Koper, 2018). For species like Tree Swallows, which communicate multiple messages in a single signal (Leonard & Horn, 2001c), partial masking will impact communication to a greater degree than species like the chaffinch (*Fringilla coelebs*), which communicate a single message over and over again (Brumm & Slater, 2006; Rosa & Koper, 2018). Thus, the communication strategy (e.g., using one call vs. several calls to communication several signals), as well as factors such as call frequency range and amplitude, dictate the severity of the impact energetic masking can have on communication.

2.2.3 Informational Masking

Noise can also interfere with the cognitive processing of a signal by distracting the recipient and by making the soundscape more complex (Kidd et al., 2008). Such cases are known as informational masking. Informational masking interferes with the receiver's ability to understand or recognize signals, but unlike energetic masking, this interference it is not due to amplitude or frequency overlap (Rosa & Koper, 2018). Instead, such masking may occur because there are too many signals being received and the receiver cannot perceive them all. In other words, signal receivers have a limited amount of attention and thus the number of stimuli they can process at one time is also limited (Dukas, 2004). Informational masking may also be a result of an attention shift that occurs when irrelevant stimuli are processed instead of the target signal (Beaman, 2005). As animals have limited attention and cognitive processing, when an extra stimulus such as noise is present, it can distract individuals and reduce their ability to process relevant signals.

While energetic masking is often presented as the primary mechanism by which noise disrupts communication, the effects of information masking may be more extensive. Informational masking can occur as result of noise at any amplitude or frequency range, while energetic masking can only occur if these characteristics overlap and overpower those of the signal (Beaman, 2005; Chan et al., 2010; Rosa & Koper, 2018). Thus, as long as noise is audible, informational masking can occur under almost any conditions (Rosa & Koper, 2018). As acoustic characteristics, notably amplitude, degrade when one moves farther way from the sound source, the ability of noise to energetically mask signals decreases with distance, while informational masking can occur well beyond the point where the noise is no longer strong enough to energetically mask the signal. Thus, informational masking has the potential to affect communication across a larger area, perhaps suggesting it is incorrect that energetic masking is more prominent (Rosa & Koper, 2018). Even though masking is generally described as either informational or energetic, it is often hard to separate the two, as they can occur at the same time and it can be hard to isolate one mechanism from the other outside of a laboratory environment (Grade & Seiving, 2016). While it can be hard to isolate informational masking from energetic masking, there is evidence which suggests that informational masking can affect communication over a wider range of circumstances.

2.3 Adjusting to Noise

Animals can use certain strategies to counter the effects of noise on communication, but their effectiveness often depends on the type of masking and the nature of the noise. Repositioning the body or head in relation to the source of the noise and signal can change the angle of the source in relation to the receiver and thus improve signal detection, especially if the receiver is angled towards the signal and away from noise (Dent et al., 1997; Rosa & Koper, 2018; Schwarts & Gerhardt, 1989). The location of signal source and the noise source can also play a role in the degree to which communication is impacted. When the source of noise is spatially separated from the signal, signal detection can be improved if species change locations to signal in an area farther away from the source of noise, it could avoid the effects of masking, particularly energetic masking (Dent et al., 1997; Schwarts & Gerhardt, 1989).

Release from informational masking can be harder to achieve as it relies more heavily on cognitive mechanisms as opposed to the nature of the signal (Rosa & Koper, 2018). Habituation to noise is one way in which individuals can overcome informational masking, as they would

become accustomed to the noise over time until it is no longer distracting. For this strategy to be effective, however, the noise would have to be continuous, because if it were to stop and start again, individuals have to be re-habituated (Beaman, 2005). Thus, outside of laboratory conditions, true habituation would likely be rare and thus marginally reduce informational masking.

Species can also alter the structure and characteristics of their signals in order to communicate more effectively in the presence of noise. Changing the amplitude and frequency of signals can reduce the effect of noise on communication. Increasing amplitude to avoid the disruption of noise is known as the Lombard Effect and has been observed as a response to noise in several species (Hanna et al., 2011; Hart et al., 2015; Potvin, 2017; Warren et al., 2006). In terms of frequency changes, species usually shift their calls into higher frequency ranges where there will be less overlap with human-caused noise which tends to occupy lower frequency ranges (Warren et al., 2006). In addition to shifting to higher frequency ranges, animals have also been observed to call at a narrower frequency range (Leonard & Horn, 2008). Using “pure tones” to signal instead of a broad bandwidth helps reduce the chances of energetic masking (Warren et al., 2006). Other changes to call structure include using simpler songs such as those with fewer call elements or increasing the redundancy of signals (i.e., repeating the same call many times), which can help ensure that relevant information is processed by the receiver (Brumm & Slater, 2006; Founda et al., 2018; Leonard & Horn, 2008). Changes to call characteristics such as increases in amplitude, shifts in frequency range and simplifying songs can help ensure effective communication in the presence of noise by avoiding energetic masking.

2.4 Avian Communication

Birds rely heavily on auditory communication and have a complex communication system. They produce some of the most structurally complex sounds of all taxa (Drew et al., 2009). Intricate songs, often with multiple variations, are relied on to find and attract mates, with call enthusiasm often influencing the female’s final decision (Byers et al., 2010). Birds communicate urgency and the threat of predators by changing the call length and the number of elements in their alarm calls and use similar features to establish dominance or defend their territory (Leavsley & Magrath, 2005; Linhart et al., 2013).

As with mating and warning calls, complex calls are used during the nesting season to communicate information between parents and offspring, from nestling hunger and thermal state

to parental contact and predator presence (Corney & Barber, 2018; Leonard & Horn, 2001a, 2001c; McIntyre et al., 2014). The communication between parents and nestlings during the nesting period is particularly important as at this time nestlings are dependent on their parents for food provisioning and thermal regulation. Begging call rates, length and amplitude communicate information about hunger to parents, signalling which nestling needs to be fed and thus impacting the order in which food is provided (Leonard & Horn, 2001a, 2001c). Increases in begging call intensity causes parents to increase provisioning rates (Corney & Barber, 2018). Nestlings also change the rate and peak frequencies of their calls to communicate their thermal state which helps indicate to their parents when more incubation is need and can signal when parents should dedicate less time to brooding and more to feeding as nestlings begin to thermoregulate for themselves (Leonard & Horn, 2001c). Nestlings may also use begging calls to communicate amongst each other (Roulin et al., 2000). As a result of nestling's vulnerability during the nesting period, effective communication between nestlings and their parents is essential to their survival.

Effective communication between parents and their nestlings also reduces the risk of nest predation. Parents use alarm calls to signal to nestlings that a predator is nearby. In response to these calls, nestlings typically stop begging and crouch down in the nest to avoid detection (McIntyre et al., 2014). Alarm calls are often species specific, allowing nestlings to distinguish their parents' alarm calls from other sounds in the environment (Davies, 2004). During the first few days of the nesting period, exposure to parental alarm calls is believed to help nestlings develop their response to the calls and familiarize themselves with the calls of their parents. Gaining such exposure likely helps them recognize their parents' alarm calls later in life and thus helps them respond to threats appropriately (Davies, 2004). Parental alarm calls play a key role in the ability of nestlings to perceive threats such as the presence of predators.

Noise can disrupt parent-nestling communication, causing important cues and signals to be missed. In noisier nests, nestling tend to beg less readily in response to parental cues compared to those in quieter nests (Leonard & Horn, 2012). Noise can also cause nestlings to increase the intensity of visual cues such as postural begging, in order to better communicate their hunger in an environment where acoustic cues are masked (Leonard et al., 2015). Nestlings have also been observed to increase begging call length, amplitude and frequency to communicate more effectively in the presence of noise (Leonard et al., 2015; McIntyre et al.,

2014). Food provisioning is not the only behaviour that is affected when noise disrupts parent-nestling communication. Noise can mask important elements in alarm calls, resulting in an incorrect response from nestlings, such as continued begging or a failure to crouch down in the nest (McIntyre et al., 2014). While calling strategies can be adjusted, the overall effectiveness of parent-nestling communication is compromised by noise.

2.5 Call Differentiation

A key element in effective avian communication is the ability to successfully differentiate between the calls of target individuals and those of other individuals. To do so, birds use certain vocal cues and call characteristics to recognise specific individuals such as mates, nestlings and parents. Even in dense colonies, birds seem to only respond to their own mates or chicks. In these cases, this differentiation is based largely on call alone (Jouventin et al., 1999). This suggests that birds look for specific call elements or cues in order to identify specific individuals. King Penguin (*Aptenodytes patagonicus*) chicks have been observed to use the frequency range of their parents' calls, specifically the low frequency portions, to distinguish their parents from other adults (Jouventin et al., 1999). Jouventin et al., (1999) found that chicks did not respond to the calls of their parents when calls were manipulated and played at a higher frequency. Using maximum and minimum frequency to distinguish between calls has also been observed in other species, such as Long-tailed Tits (*Aegithalidae*) (Sharp et al., 2005). In cases like these, only the syllables that contain important inflections points, the point between an increase and decrease in frequency, are needed for recognition (Chen et al., 2020; Jouventin et al., 1999). In other cases, all of the call syllables are required for the complete recognition of the signal. When syllables are absent, the receiver may not respond to the same degree as they would when all of the syllables are included (Soha & Whaling, 2002). As indicated above, birds rely on a variety of important structural components to help distinguish between calls.

Given the use of calls to recognize individuals, presumably the more similar the calls are, the more difficult it is for receivers to correctly distinguish between them, but there is surprisingly little evidence for that. In some cases, it appears that call similarity actually helps with call recognition. Colombelli-Négre et al. (2016) found that when Red-backed Fairywren (*Malurus melanocephalus*) nestlings produced calls that were more similar to that of the female, it resulted in an increase in feeding rate. Other evidence indicates that call similarity is a hindrance to identifying an individual. For example, nestlings have been observed to respond to

an unfamiliar adult when the calls of the other adult and that of their parents are acoustically similar (Reers et al., 2013). Birds have also been observed to respond to the unfamiliar alarm calls of other species when they are acoustically similar to their own species' alarm calls (Fallow et al., 2011). While in this case, misidentifying an individual would be advantageous, as it could induce an earlier threat response, misidentification does not always yield a positive result.

Parents who misidentify their nestlings can accidentally direct parental care towards nestlings that are not their own, leaving them with lower feeding rates or missed feedings. By misidentifying their nestlings, parents may accidentally feed other nestlings and not their own (Leonard et al., 1997; Reers et al., 2013). Errors in identifying nestlings can also result in the failure of parents and young to reunite (Reers et al., 2013). This is a particular concern in colonial species, such as penguins, where parents must find their chick upon their return to the colony after a foraging trip (Jouventin et al., 1999). Failing to do so would result in missed feedings. In extreme cases such as nest parasitism, misidentifying one's young can lead to significant decreases in parental care or even the death of their young. Cuckoo (*Cuculidae*) nestlings have been observed to mimic the begging strategies of their host species' nestlings in order to elicit the same parental feeding rate as observed in nests not affected by a Cuckoo (Kilner et al., 1999; Lichtenstein & Sealy, 1998). For parents, the cost of misidentifying young can result in misdirected care and potentially lower breeding success.

For nestlings, responding to an unrelated adult can result in an extra feeding but there are also negative consequences that can arise from such a response. Nestlings that beg in response to nonparental calls can incur social punishment from unrelated adults (Reers et al., 2013). In some cases, however, nestlings can receive extra food as a result of calling to unrelated adults, in effect, cheating the normal provisioning rules (Reers et al., 2013). Predation is a risk that is associated with begging and as such, nestlings who call in response to an unrelated adult, not only risk social punishment but may also increase the risk of predation (Leonard et al., 2005; McIntyre et al., 2014; Reers et al., 2013). Similarly, if nestlings fail to recognize their parents' calls, they can miss warnings about predators and potential threats (McIntyre et al., 2014). While it may result in an extra feeding, nestlings that misidentify their parents also risk being attacked by other adults and attracting predators.

2.6 Knowledge Gaps

Currently, there are few studies that seek to understand how acoustic similarity impacts the ability to distinguish one call from another in the presence of noise. Few studies have investigated how call similarity affects call recognition and discrimination or how noise impacts discrimination. To my knowledge, none have sought to understand the impact both noise and call similarity have on call discrimination. Identifying these effects are important as identification errors can impact signal design, such as the number of call elements or call frequency (Reers et al., 2013). In particular, more research is needed on how call similarity affects the ability of nestlings to distinguish between their parents and other adults, as nestling survival often relies on the successful communication between nestlings and their parents. One study has investigated how nestlings respond to calls which are similar to their parents'; however, it was performed under laboratory conditions and thus did not take into account other environmental factors that may interfere with call discrimination such as noise (Reers et al., 2013). Another looked at how noise affects nestling call discrimination, but did not explore the role of call structure (i.e. call similarity) in discrimination (Horn et al., 2020). A study looking at the effects of acoustic similarity on call discrimination in the presence of noise needs to be done to better understand how noise impacts call discrimination, especially in nestlings.

2.7 Conclusions

This literature review has outlined how noise, specifically anthropogenic noise, impacts wildlife communication. It has discussed the mechanisms by which noise can disrupt communication and how animals change their behaviour to avoid this disruption. Throughout this review, the importance of understanding how noise impacts communication, especially between parents and offspring has been highlighted. Noise is becoming more prevalent, and expanding its area of impact. Understanding how noise impacts wildlife is important for future conservation considerations, especially in taxa with complex communication systems such as birds. It is widely believed that noise disrupts the communication between individuals by masking important signals, distracting recipients and causing recognition errors. There is still a need for further research into how call similarity affects discrimination in the presence of noise to better understand how noise impacts call discrimination.

3.0 Methods

This study used the data on nestling response recorded during Horn et al.'s (2020) study in 2016. The methods used in that study (measuring nestling responses) are briefly summarized here, followed by the specifics of the present study (measuring call similarity and relating it to responses).

3.1 Study Species

Tree Swallows are a passerine species (more commonly known as “songbirds”) that typically live in open spaces near water bodies and are aerial insectivores, meaning they primarily eat flying insects (Winkler et al., 2020). They are semi-colonial and prefer to nest near other pairs, although nests are typically 10-15 m apart (Robertson & Rendall, 1990). Tree Swallow pairs nest in existing cavities, such as those left by woodpeckers, and thus will readily nest in human-made nest boxes (Winkler et al., 2020). Their willingness to nest in such boxes enables easy access to nestlings and parents, so their behaviour can be observed throughout the nesting period. It also allows for the manipulation of the nest environment, in this case an increase in ambient noise level. Swallows, including Tree Swallows, have often been used in research exploring parent-offspring communication and recognition (Halpin, 1991).

3.2 Sampling Design

The data were collected at four study sites in the Gaspereau Valley, just outside of Wolfville, Nova Scotia, Canada between May and July of 2016 (Figures 1 & 2). It was collected using a non-probabilistic sampling scheme in which the rearing treatment (quiet or noise) was randomly assigned to each nest, after nests were matched for hatch date and brood size. The treatment group was made up of 30 nests and the control group contained 46 nests. Nestlings in the treatment group were exposed to 65dBA computer-synthesized white noise through an earbud in the nest from day 3 to day 15 post-hatch. Playback tests were administered on day 16. Parental provisioning calls were played 30 seconds after a feeding visit, followed by 2 minutes of silence. After the 2 minutes of silence, the same number of provisioning calls of the other adult in the call pair were played. The playback tests were administered under two conditions: noise and quiet. For the noise condition, white noise was played through earbuds starting 30 minutes prior to the playback test and ending two minutes after the tests were completed. The order of playbacks and conditions was counterbalanced across nests, with random assignment of each order to individual nests. The response data included begging calling duration (s) and a begging score, which applied a scale of increasing intensity from one to five, with one being gaping only

and five being gaping, head up, neck stretched upward, body lifted and wings moving (Horn et al., 2020).

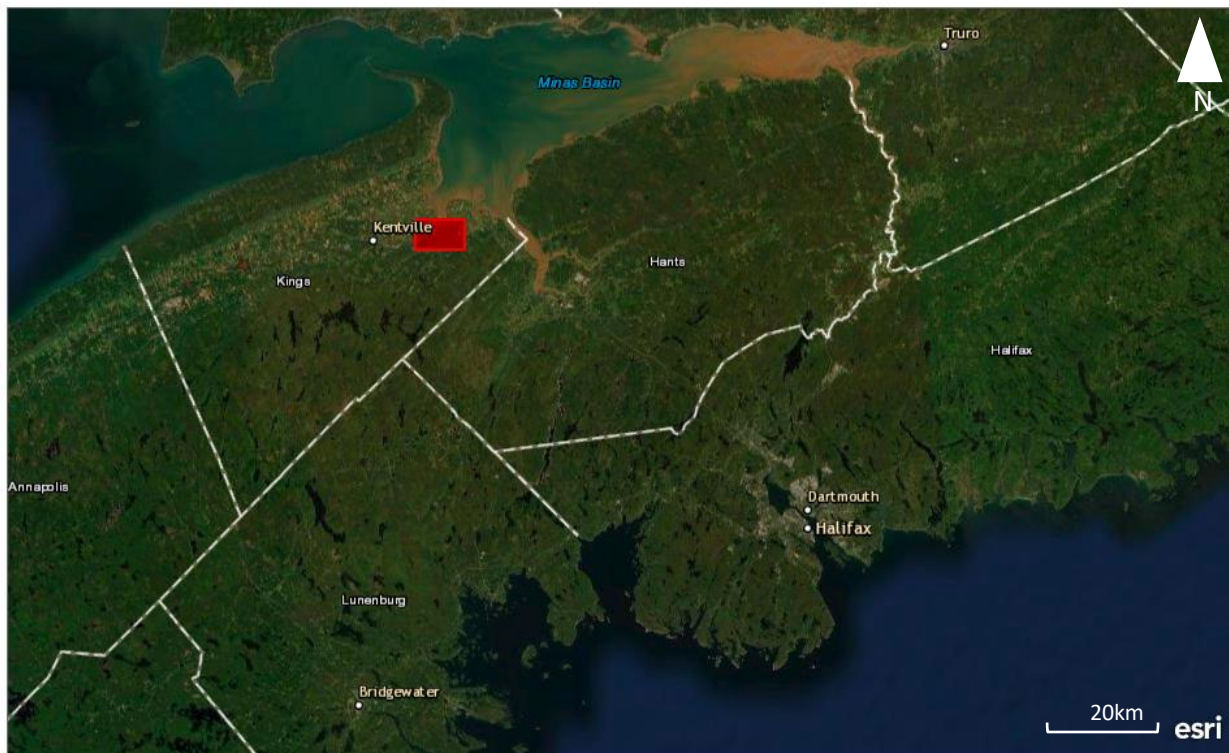


Figure 1. Wolfville and Gaspereau valley region (red) in relation to Halifax, Nova Scotia (Created in ArcOnline - Esri, 2020).



Figure 2. Location of study sites (A,B,C,D) in the Gaspereau Valley, Nova Scotia Canada (Created in ArcOnline - Esri, 2020).

3.3 Data Collection

The difference in begging score and calling duration in response to the parental call and another adult's call were calculated. Positive values are assumed to indicate “correct” cases, because nestlings responded more strongly to their parent's call, while negative values indicate “incorrect” cases, because nestlings responded stronger to the other adult's call.

Two similarity measures were collected from the playback calls: Euclidean distance and spectrogram cross-correlation. Euclidean distance is a multivariate measure which measures the distance between two points, or in this case, calls. Eight call characteristics were measured for each call using Raven Pro 1.6 (Center for Conservation Bioacoustics, 2019). These characteristics were peak frequency contour (PFC) average slope, bandwidth (frequency range), call duration, aggregate entropy, average entropy, centre frequency, the residuals of the PFC number of inflection points and the centre point (centre time/duration). Intercorrelations between all eight characteristics were examined, and aggregate entropy was removed because of its high correlation ($r > 0.7$) with bandwidth. After the highly correlated values were removed, seven final call characteristics were used (Table 1). Each measure was standardized using z-scores in Excel and Euclidean distance was calculated using RStudio, an extension of the R 4.0.3 software (RStudio Team, 2020).

Table 1. Final seven characteristics extracted from each call using Raven Pro and their descriptions.

Call Characteristic	Description
<i>Peak Frequency Contour (PFC) Average Slope</i>	The average rate of change in frequency across the call.
<i>Bandwidth</i>	The frequency range (frequency 95% – frequency 5%).
<i>Call Duration</i>	The length of the call (time 95% - time 5%).
<i>Average Entropy</i>	The average “noisiness” of the call.
<i>Centre Frequency</i>	The frequency point where half of the call's energy occurs above, and half occurs below.
<i>The Residuals Number of PFC Inflection Points</i>	The difference between the observed number of inflection points and the expected number of inflection points in a call, based on a regression of inflection points versus call duration across all calls.
<i>The Centre Point</i>	The centre time (the point where 50% of the call occurs before and 50% occurs after) divided by call duration.

Raven Pro was also used to calculate the second measure of similarity, a spectrogram cross-correlation. A spectrogram cross-correlation aligns two spectrograms on the time axis to

find the maximum overlap between them and calculates their correlation in spectrum level (amplitude) at that time, across all points in the spectrogram, as a measure of how similar the calls are. Unlike Euclidean distance, spectrogram cross-correlation is a holistic measure that looks at calls in their entirety. While it has been used in other studies to determine call similarity, it is a simple and narrowly defined measure and should not be used for generalized pattern recognition, but is still useful as a complementary approach to Euclidean distance (Colombelli-Négrel et al., 2016; Charif, Waack, & Strickman, 2010; Ranjard et al., 2010).

3.4 Data Analysis

Four General Linear Mixed Models (GLM's) were used to model the relationship between call similarity and nestling response in the presence of noise. As a GLM allows for the inclusion of multiple independent variables as well as any potential interactions between those variables, it was hoped that these models would be able to capture the influence of both call similarity and noise on call discrimination. The similarity measures, rearing treatment (quiet vs. noise) and testing condition (quiet vs. noise) were used as fixed factors while the nest was used as a random factor and all model assumptions were met. Jamovi (The jamovi project, 2021), an extension of RStudio was used to generate each GML.

3.5 Potential Limitations and Sources of Error

Temporal constraints during data collection are a limitation of this study. As discussed above, the data were collected in one year (2016) from May to July. The monthly window is not a particularly important limitation, as this is the Tree Swallow nesting period in Nova Scotia, so there are no alternative times in which data could have been collected. The yearly time constraint means that it cannot be stated for certain that observations in this study would be observed in a different year. As this study focuses on fundamental behaviours, however, it is unlikely that the observations would differ significantly from year to year.

The spatial constraints of data collection also present a similar limitation. The four sites used to collect data are part of a long-term study site and thus, have been used in many past research projects, many of which explore the impact of noise on Tree Swallows and have proven to be reliable sources of study subjects (Leonard & Horn, 2008; Leonard et al., 2015; Leonard & Horn, 2012; McIntyre et al., 2014). As with the temporal limitations, the spatial constraints are not expected to compromise the generalizability of the results, given that this study investigates fundamental behaviours.

Another potential limitation is the use of white noise rather than other anthropogenic noise (Horn et al., 2020). There are advantages to using white noise instead of other noise but there are also drawbacks. White noise consists of random amplitude variation at wavelengths throughout the audible frequency range (20 to 20,000 Hz). Its broad bandwidth gives white noise the potential to energetically mask playback calls to a greater extent than other anthropogenic noise, which would most likely occupy a narrower frequency range (e.g., peak frequencies for highway traffic noise typically occur around 1,000 Hz) (Rochat & Reiter, 2016). A drawback, however, is that using white noise reflects a less natural acoustic environment. For example, using traffic noise could simulate conditions occurring in a roadside nest and more accurately indicate how these conditions impact call recognition than using white noise would. In this case, however, by using white noise more frequency ranges are occupied, thus increasing the likelihood of energetic masking.

A potential source of error exists in the analysis of the call recordings, as background noise may interfere with Raven Pro's ability to extract accurate measurements (Charif, Waack, & Strickman, 2010). This is a particular concern with the spectrogram cross-correlation, as it may make it appear that certain calls are more similar or different than they are actually are (Charif, Waack, & Strickman, 2010). With this being said, the recordings were amplified, and high-pass filtered at 500Hz with a 12dB roll off during Horn et al.'s (2020) study to remove the majority of background noise. To further reduce the impact of background noise on the correlation output, the spectrogram cross-correlation was run through a 35 dB filter, so any sounds occurring below 35 dB would not be included. These measures will help prevent background noise from interfering with correlation calculations.

4.0 Results

The largest Euclidean distance between call pairs was 6.00 and the smallest distance was 1.90. The highest spectrogram cross-correlation value was 0.65 and the lowest correlation value was 0.023. None of the four models showed a significant ($p < 0.05$) effect on nestling response under any rearing or playback conditions (Table 2, Figures 3 & 4).

Table 2. GLM's testing effects of call similarity, rearing and testing conditions on responses of nestlings to parental provision calls. The sample size for calling duration is smaller as not all broods called.

Response Variable	Effect	<i>F</i>	<i>df</i>	Estimate	95%CI	<i>P</i>
Begging Score						
	Euclidean Distance	0.06	1, 72	0.027	-0.20, 0.25	0.81
	Rearing Condition (noise/quiet)	1.38	1, 72	-0.29	-0.76, 0.19	0.24
	Playback Condition (noise/quiet)	1.70	1, 72	-0.30	-0.76, 0.15	0.20
	Rearing*Playback	0.34	1, 72	-0.27	-1.18, 0.64	0.56
Calling Duration						
	Euclidean Distance	0.00	1, 35	-0.096	-3.65, 3.46	0.96
	Rearing Condition (noise/quiet)	2.00	1, 35	-5.35	-12.77, 2.06	0.17
	Playback Condition (noise/quiet)	0.82	1, 35	2.02	-2.35, 6.39	0.37
	Rearing*Playback	1.78	1, 35	-5.94	-14.69, 2.80	0.19
Begging Score						
	Spectrogram Cross-correlation	1.64	1, 72	0.99	-0.52, 2.51	0.20
	Rearing Condition (noise/quiet)	1.89	1, 72	-0.32	-0.78, 0.14	0.17
	Playback Condition (noise/quiet)	1.71	1, 72	-0.30	-0.75, 0.15	0.20
	Rearing*Playback	0.36	1, 72	-0.28	-1.18, 0.62	0.55
Calling Duration						
	Spectrogram Cross-correlation	0.54	1, 35	8.87	-14.89, 32.64	0.47
	Rearing Condition (noise/quiet)	2.57	1, 35	-5.94	-13.21, 1.33	0.12
	Playback Condition (noise/quiet)	0.83	1, 35	2.03	-2.34, 6.40	0.37
	Rearing*Playback	1.79	1, 35	-5.96	-14.70, 2.78	0.19

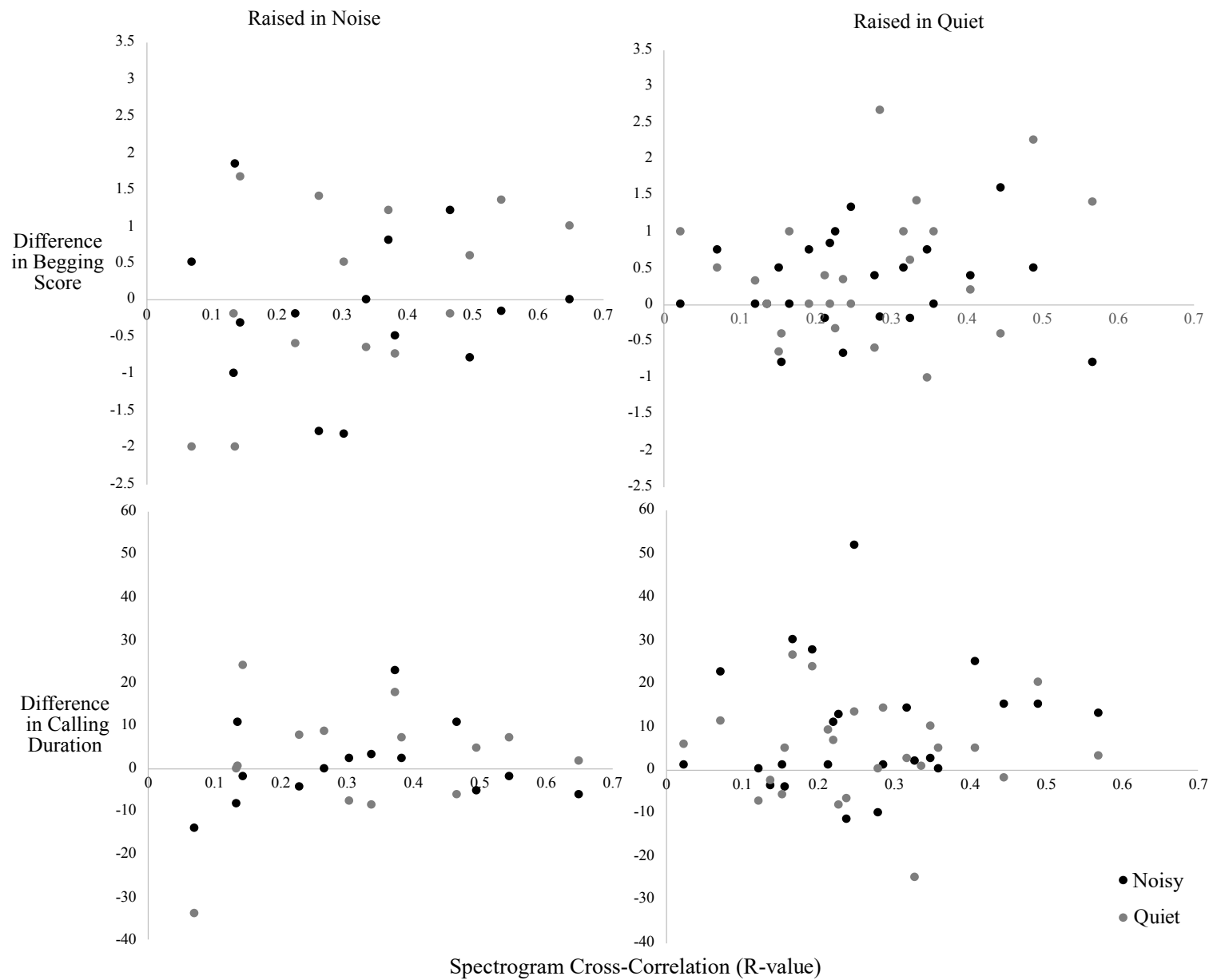


Figure 3. The spectrogram cross-correlation (r-value) in relation to the difference in begging score and calling duration for nestlings raised in noisy and quiet conditions for each playback test (noisy conditions in black, quiet conditions in grey).

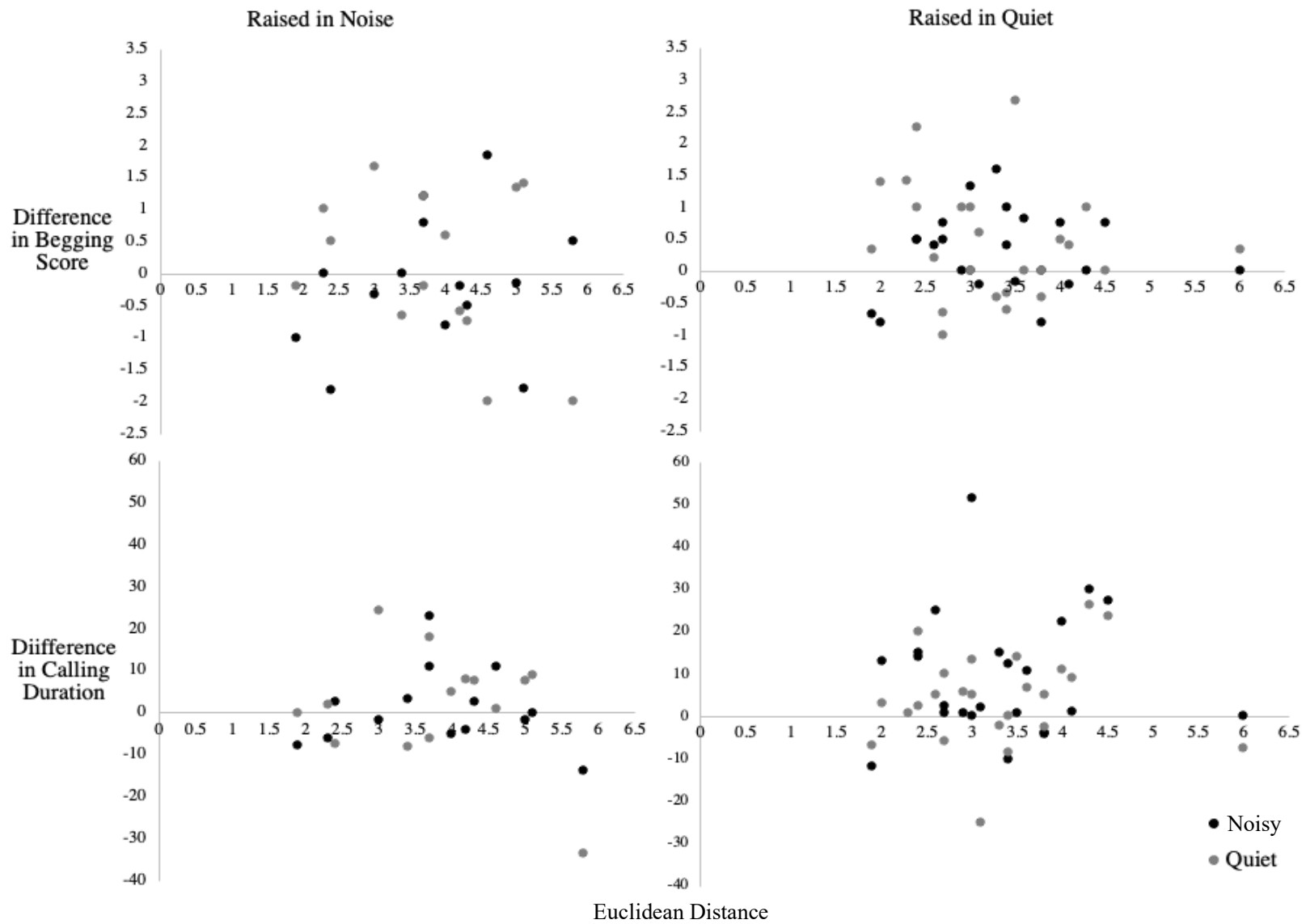


Figure 4. The Euclidean distance in relation to the difference in begging score and calling duration for nestlings raised in noisy and quiet conditions for each playback test (noisy conditions in black, quiet conditions in grey).

5.0 Discussion

Contrary to what was predicted, the results of my study suggest that call similarity does not have a significant impact on call recognition, regardless of the conditions under which the nestlings are raised or in which the calls are played. Post-hoc analysis of the correlations between call similarity and responses for each combination of rearing and testing conditions indicated that only one subset showed trends in the predicted direction: among noise-reared nestlings tested in noisy conditions, when the Euclidean distance between call pairs increased, the difference in begging score increased (Table 3, Figures 3 & 4). In other words, the more dissimilar the calls, the stronger the nestling response to their parents call in the presence of noise. The trend was not significant, however, and no other models showed trends in the predicted direction.

Table 3. The correlation between each subset of conditions in both rearing treatments. All coefficients were insignificant ($p < 0.05$).

Rearing Condition	Playback Condition	Similarity Measure	Response Variable	Correlation Coefficient
Noise	Noise	Euclidean Distance	Begging Score	0.296
		Spectrogram Correlation	Begging Score	-0.053
		Euclidean Distance	Calling Duration	-0.045
		Spectrogram Correlation	Calling Duration	-0.053
	Quiet	Euclidean Distance	Begging Score	-0.004
		Spectrogram Correlation	Begging Score	0.255
		Euclidean Distance	Calling Duration	-0.004
		Spectrogram Correlation	Calling Duration	0.255
Quiet	Noise	Euclidean Distance	Begging Score	0.060
		Spectrogram Correlation	Begging Score	0.044
		Euclidean Distance	Calling Duration	0.041
		Spectrogram Correlation	Calling Duration	0.119
	Quiet	Euclidean Distance	Begging Score	-0.189
		Spectrogram Correlation	Begging Score	0.278
		Euclidean Distance	Calling Duration	0.138
		Spectrogram Correlation	Calling Duration	-0.022

It is possible, of course, that the response measures in my study, calling duration and begging score, fail to capture the relationship between call similarity and nestling response. Reers et al. (2013) observed that nestling responses to the call of a parent were louder and occurred at a higher frequency than responses to the calls of unfamiliar adults. In my study, too, call similarity may not impact postural begging and calling duration, but may induce other changes in nestling response. If so, then call similarity may still impact nestling recognition, even though the results in my study were not significant.

Another explanation for the lack of significant results may be that nestlings are so skilled at recognizing their parent that only a high degree of similarity can induce recognition errors (Reers et al., 2013). Thus, the degree of similarity for each call pair in my study may have been too low to induce a recognition error, or the pairs were not similar enough in the call elements used by the nestlings for recognition. For example, Jouventin et al., (1999) showed King Penguin chicks have a harder time distinguishing between calls that are similar within certain bandwidths. If the call pairs were not similar within those bandwidths, nestlings would still be able to recognize their parents call, even if the rest of the call was very similar.

This reasoning may also indicate why noise had no significant impact. As with similarity, if the noise did not occur at the same frequency as the bandwidth containing the identifying elements, such elements would not be energetically masked. Fallow et al., (2011) suggest that call elements which occupy higher frequency ranges, such as peak frequency, are used in call recognition because they are less likely to be energetically masked by unrelated signals. The parental calls used for the playback tests were also the calls of the female parent, which typically occur at a higher frequency than male calls (Horn et al., 2020; Leonard et al., 1997). If nestlings use higher frequency call elements to distinguish between calls, the high frequency calls of the female parent could minimize the energetic masking of key call elements, allowing the nestlings to recognize the calls more easily. A release from energetic masking would leave only informational masking to interfere with call recognition, but as it is theorized that in this study the nestlings would be somewhat used to the presence of constant noise, the impact of informational masking is expected to be minimal.

The results of my study, which are supported by the observations made by Horn et al., (2020), suggest regardless of auditory conditions (i.e., noisy or quiet), nestlings can still use specific call elements to distinguish between calls. There are a number of ways this might

happen. One such way is that nestlings selectively tune into features that are unchanged by noise (Mouterde et al., 2017). By doing so, nestlings would be able to identify their parents calls, regardless of their acoustic environment. Another potential way in which nestlings access identifying call elements is by increasing their sensitivity to those features in the presence of noise or by decreasing their sensitivity to the unchanging noisy background (Appletants et al., 2005). While decreasing their sensitivity to the continuous noise may be applicable to this study in which the nestlings were exposed to continuous white noise, it may not be an accurate reflection of how nestlings distinguish calls in a more natural setting, where noise can occur sporadically and fluctuates in frequency and amplitude. Regardless of the mechanism they use, the ability of nestlings to successfully identify their parents in the presence of noise is impressive

The impacts of noise also vary with age, so the timing of the playback tests is relevant (Leonard et al., 1997). The playback tests were administered when the nestlings were 16 days old (Horn et al., 2020). Older nestlings would have had a longer time to familiarize themselves with their parents' calls and adjust to the presence of noise. If so, this familiarity could explain why rearing and playback treatment had no significant effect on responses. It would, however, suggest that it would be more difficult for nestlings raised under quiet conditions to identify their parents, which was not the case. Nevertheless, had the tests been administered when the nestlings were younger, the results may have differed from those seen in my study.

The results of my study add to the existing body of evidence that suggests that, even when calls are unfamiliar, individuals respond to calls in some way. In some cases, the response can be as simple as scanning the area for predators after hearing a dissimilar alarm call (Fallow et al., 2011), while in others it can be more extensive, such as calling to an unrelated adult (Reers et al., 2013). In the latter case, Reers et al. (2013) suggests three reasons why nestlings may respond to unfamiliar adults. The first is true recognition errors. Such errors occur when the nestling truly mistakes the unrelated adult for their parent (Reers et al., 2013). The second is that the nestlings are following a cheating strategy (Reers et al., 2013). In such cases, it may be that the nestling detects that the unrelated adult is not their parent, but begs anyway to receive extra food. This can be costly, however, as it can result in social punishment from the unrelated adult and attract the attention of predators (Reers et al., 2013). The third reason proposed by Reers et al. (2013) is that nestlings recognize that the unfamiliar adult is not their parent, but call anyway to develop social interaction skills. Such skills are beneficial later on in their life history, in

situations such as maintaining contact within a flock (Zann, 1996). Each of these reasons may indicate why there was no significant difference between nestling responses in any of the treatment groups when calls were more similar. These three reasons are hard to disentangle and neither my results nor those of Reers et al. (2013) can exclude any of them as explanations as to why nestlings responded as they did.

5.1 Future Research

The results of my study highlight several areas in need of further research. First, a study using the same treatment conditions as my study (i.e., raised in noise or quiet and playback tests under both noisy and quiet conditions) should be conducted, however, rather than using random call pairs for the playback tests, the study should use call pairs that are (or are artificially manipulated to be) highly similar. As nestlings are very skilled at recognising their parents calls, using pairs that are highly similar may better indicate the impact call similarity and noise have on call recognition than the results from my study. Additional response data, such as nestling call structure (i.e., amplitude, frequency range, etc.), should also be recorded to ensure a more complete picture of the impact of call similarity and noise on nestling response.

The exact mechanism and elements nestlings use to distinguish between individuals remains largely unknown (Reers et al., 2013). Pinpointing this mechanism could provide insight into how nestlings successfully identify their parents when calls are similar and in the presence of noise. Once identified, research would be needed to identify what happens when call similarity and noise disrupt this mechanism. Such research could also identify potential threats to call recognition. For example, if the call element used is peak frequency, noise that occupies higher frequency ranges has the potential to negatively impact nestling call recognition to a greater extent than noise occupying lower frequency ranges (Jouventin et al., 1999).

Finally, it is unclear how nestling response would change in the presence of inconsistent noise. In my study, nestlings were constantly exposed to white noise at a consistent amplitude of 65 dB (Horn et al., 2020). Noise that fluctuated in amplitude, frequency or time played could induce different nestling responses to the ones seen in my study (Horn et al., 2020). This could be because the nestlings would not be able to become accustomed to the constantly changing noise, making it more distracting during the playback tests. Such results have been observed in studies of learning in children (Woolner & Hall, 2010). In contrast, nestling stress levels in European Starlings (*Sturnus vulgaris*) have been observed to be higher in control groups exposed

to ambient noise that was intermittent and unpredictable than under constant, unchanging condition such as the ones in my study (Walthers & Barber, 2019). Using varying noise may also provide a more nuanced understanding of how noise impacts call recognition. It could present new thresholds in terms of what the acoustic characteristics need to be for noise to have an impact on call recognition or it could indicate that the impact of noise gradually changes as those characteristics do.

6.0 Conclusions

Neither call similarity nor noise had a significant impact on nestling response in my study, which was contrary to my predictions. With this in mind, there are three key considerations that should be remembered when understanding the non-significance of my results. My study was based on visual cues (postural begging score) and calling duration, and thus fails to capture how the acoustic structure (e.g., frequency, amplitude etc.) of nestling responses to parental calls differs from the response to other adults. The use of consistent and constant noise for the rearing treatments and playback tests may also account for my negative results, as nestlings may have become semi-habituated to the presence of noise. Finally, the exact mechanism by which nestlings use to distinguish between calls remains unknown. Identifying this mechanism will create a better understanding of how nestlings distinguish between similar calls both in quiet and noisy conditions. Future research should address these considerations in order to create a more nuanced understanding of how call similarity impacts call recognition in the presence of noise.

It is important to remember that, while its impact may not have been significant in my study, we should still pay close attention to the impacts of noise, especially when it comes to the more detrimental impacts of noise. For example, amplitudes of 80dB and higher can damage nestlings' ears, and can cause permanent hearing loss (Dooling, Dent, Lauer, & Ryals, 2008). Permanent hearing loss would alter a bird's ability to hear calls and predatory threats, and for species that rely heavily on hearing to hunt, such as owls, the consequences of hearing loss could be especially damaging. Noise can also induce elevated stress levels and can impact the immune system development in nestlings, particularly the smallest nestlings, which are often already vulnerable (Obomsawin, 2020). Thus, taking a precautionary principle approach to noise, especially anthropogenic noise, by considering it in conservation planning will help ensure its impacts are minimized.

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