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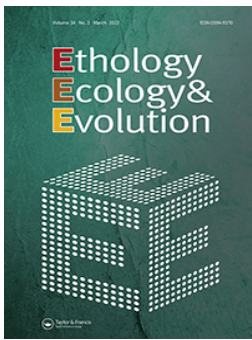
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Urban junco flight initiation distances correlate with approach velocities of anthropogenic sounds

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Urban-dwelling birds face novel visual cues and soundscapes. To thrive in these challenging environments, individuals must correctly identify and calibrate threats posed by humans and their activities. We showed that Dark-eyed juncos (*Junco hyemalis*) residing in an urban habitat responded differently to the sounds that approaching people and objects make. A person approached juncos simultaneously playing the sounds of object types that normally move at different relative velocities: faster (bicycles), intermediate (skateboards and scooters), or slower (people walking). Juncos responded at significantly greater distances and moved further in relation to what sound cues would normally imply about the velocity of approach. Absolute stimulus volume was not a significant predictor of response across object type. The responses occurred without the presence of visual cues, suggesting that an auditory cue alone and without visual confirmation can produce an appropriate response. Overall, this shows that this population of urban juncos has the ability to respond appropriately to novel anthropogenic sound cues. The question remains as to how universal such abilities are across species, different urban situations, and in natural habitats.

KEY WORDS: *Junco hyemalis*, urban ecology, flight initiation distance, auditory cues, risk, multimodal signals.

INTRODUCTION

Urban environments challenge birds in very specific ways – through differing climates, new food sources and nesting sites, changed auditory soundscapes, and different predators and competitors (Yeh & Price 2004; Chace & Walsh 2006; Partecke et al. 2006; Warren et al. 2006; Møller 2008, 2010; Schlesinger et al. 2008; Nemeth & Brunn 2010; Møller & Ibáñez-Álamo 2012; Strasser & Heath 2013; Aronson et al. 2014; Mikula 2014; Battle et al. 2016; Pavisse et al. 2019). While some differences, such as increased

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food from bird feeders (Reynolds et al. 2017), make life significantly easier, other urban features are challenging. For example, loud traffic noise can affect vocal communication with conspecifics (Halfwerk & Slabbekoorn 2014; Walters et al. 2019). Furthermore, benefits and costs could be differentially distributed spatially. Not all individuals have access to feeders (Galbraith et al. 2017; Reynolds et al. 2017), and individual territories vary in noise levels (Wood & Yezerinac 2006).

One of the most obvious and ubiquitous of urban features is the presence of humans. High human density and activity can require considerable adjustment in vigilance and anti-predator behavior (Fernández-Juricic et al. 2001; Frid & Dill 2002; Mikula 2014). Overly sensitive birds may fail in cities because they spend too much time avoiding humans that pose little to no actual risk. On the other hand, birds may not respond to real, but novel threats. How birds determine what is a real risk could substantially affect success in urban environments.

Flight initiation distance (FID) and distance moved are common measures for how birds perceive and respond to threats (Blumstein 2003, 2006). More fearful birds have larger distances than less fearful ones in response to interactions with humans and this can be used to compare populations (García-Arroyo & MacGregor-Fors 2020). Urban populations have measured FIDs that are generally shorter than those measured in natural habitats (Partecke et al. 2006; Møller 2008; Atwell et al. 2012; Díaz et al. 2015; Battle et al. 2016; Samia et al. 2017). There can also be more specific differences in observed behavior. For example, urban birds respond similarly to being directionally and tangentially approached, whereas rural birds respond more strongly to directional approaches (Møller & Tryjanowski 2014). Pigeons and corvids in urban areas appear to recognize individual human faces and more willingly approach and inspect human-produced litter (Stephan et al. 2012; Greggor et al. 2016). The socialness of pigeons and corvids may be a key facilitating behavior increasing their success in cities (Skandrani et al. 2016, 2017).

Under natural conditions auditory cues also affect bird behavior; for instance, chickadees and blue tits respond differently to a hawk model depending on if hawk calls are simultaneously played or not (Billings et al. 2015; Carlson et al. 2017). Anthropogenic noises are very recent and urban dwelling birds may or may not be finely attuned to all the novel features. The frequency and volume of urban sounds can affect communication efficiency and in response, urban species do appear to alter vocal characteristics (Wood & Yezerinac 2006; Halfwerk & Slabbekoorn 2014; Moseley et al. 2018; Deoniziak & Osiejuk 2019; Walters et al. 2019; Juárez et al. 2021). In all likelihood, specific features of urban environments produce unique and, therefore, potentially diagnostic sounds. For example, people walking towards birds will sound different than those approaching on bicycles. Given that reaction times to bicycles should be much shorter than reaction times to walkers, their sounds can be informative signals as to when to move. Thus, urban birds may use multimodal sight and sound cues (Munoz & Blumstein 2012), to assess threats posed by approaching objects.

In this study, we measure the flight responses in an urban population of Dark-eyed juncos (*Junco hyemalis*) to the stereotypical sounds that oncoming objects make. We predict that responses will reflect information contained in the anthropogenic sounds that correlate with expected approach velocities. Specifically, birds should move out of the way earlier and perhaps move farther when confronted with an auditory cue that implies a rapid approach (Table 1).

Table 1.

Mean decibel level of pre-recorded sounds played while approaching birds. Walk on grass is equivalent to recording University of California campus background noise. Smooth and rough refers to the state of the pavement over which the sound was recorded. Sounds differ in their meaning as regards to the rate at which a person or object could be approaching. Relative loudness is calculated as the decibel level of a given stimulus moving over a particular terrain, divided by lowest decibel level made the same object moving over any of the possible terrains (e.g., walking on dry leaves/walking on grass).

Stimulus	Decibel level	Relative loudness	Likely approach velocity
Walk on grass	51.4	1	Slower
Bicycle (smooth)	56.7	1	Faster
Bicycle (rough)	66.2	1.17	Faster
Scooter (smooth)	67.9	1	Intermediate
Walk on dry leaves	68.1	1.32	Slower
Walk on gravel	69.6	1.35	Slower
Scooter (rough)	74.1	1.09	Intermediate
Skateboarder (smooth)	74.6	1	Intermediate
Skateboarder (rough)	81.6	1.09	Intermediate

METHODS

Study species and site

Juncos are a small passerine bird that typically lives and breeds in forest habitats (Nolan et al. 2002). They have recently colonized and are flourishing in coastal urban habitats throughout southern California (Yeh & Price 2004; Atwell et al. 2012). One observer (K. Lukas) collected response data on 12 uniquely banded male juncos within the largely urban University of California (UCLA) campus between August and early September, 2018. UCLA is located in the northwest portion of the Los Angeles Basin (34.0695°N, 118.4452°W) at ~ 100 to 150 m asl. The 170 ha campus contains a mix of mostly non-native plant species such as eucalyptus (*Eucalyptus* spp.) and Moreton Bay fig (*Ficus macrophylla*), with large patches of lawn. Pedestrian activity occurs all year on campus and fluctuates daily in accordance with class schedules. Most people walk between buildings, but skateboarders, non-electric scooters and bicyclists are common as well.

Sampling and analysis

The observer flushed birds on the ground that were foraging or otherwise at ease (e.g., not alarm calling or agitated near a nest), using standard protocols (Frid & Dill 2002; Blumstein 2006; Martín et al. 2008; Møller 2008). The observer approached a focal individual in a straight line, dropping markers at locations where the approach began (the starting distance), where the observer was when the focal subject clearly moved away, and the distance to the spot from where that movement happened (the FID). Using the location from which birds flee avoids FID being confounded by incidental foraging movements. FIDs were measured based on converting steps between markers to meters (1 step = 0.85 m, as measured during training before the experiment). To avoid eliciting further escape behavior, we visually estimated the distance moved away in meters as the Euclidian distance determined by the horizontal and vertical distances the bird travelled. The

immediate distance of targeted birds to cover (either bushes and trees, or structures such as walls and outdoor furniture) was recorded at the point in time when the approach began.

K. Lukas (wearing typical attire relative to campus pedestrians – and without any bright colors) approached the birds and did so at the same, practiced pace for all observations (≈ 0.5 m/ sec). This rendered any physical features of the human observer to be a constant in the experiment. Birds were always approached when on the ground and exposed from vegetation, with no obstacles or other juncos (such as fledglings) between the observer and the focal bird. This protocol ensured consistent, readily detectable approaches that were as identical as possible across each bird (Frid & Dill 2002; Fernández-Juricic et al. 2004; Samia et al. 2016; Tätte et al. 2018).

Each bird experienced nine different sound stimuli (Table 1). Each recording (10–15 sec in length) was made using the Voice Memos app for smart phones as an MPEG-4. K. Lukas recorded the sounds while riding a bike, scooter, skateboard, or walking, in the presence of ambient background noise (i.e., without any extraneous sounds that might signal danger such as car horns, or singing or alarm-calling birds). Thus, the recordings themselves were of a constant activity and not of an object approaching or passing by. Hence, the sound of an "approaching" stimulus was entirely created by the experimenter advancing towards the focal bird. Each stimulus type was replicated 2 to 3 times: in a quieter state when moving over smooth terrain such as a flat sidewalk, or a noisier state when moving over rough terrain such as a textured sidewalk or dry leaves. This captures a range of noise that such moving objects may often make in an urban setting. Playbacks were from the phone at same set volume level, held at same height, and perpendicular to the ground. Phones, rather than speakers or other large equipment, were used so that the advancing person would not look unusual. Because the played recordings would meld into the existing soundscape of the immediate area in UCLA where the approach occurred, the total auditory environment of each approach would not have been completely identical. Birds were not approached, however, in areas where construction or some other loud sound would have affected the ability to hear the recordings.

Decibel X, a noise meter application (https://skypaw.com/decibel10.html 30–130 dba; time weightings 200–500 msec), was used to determine the mean loudness of each noise type across the duration of the recording when played. For each approach, the sound was turned on at the start of the approach and off when the bird moved away, which always occurred before the recordings ended. All birds were approached 5 consecutive times in a given day with the same sound playing (= 9 days of trials with 45 total approaches per bird). To get a complete series of 9 days of stimuli presentations varied across birds; ranging from 16 to 34 days in total, with a mean of 27.4 days and a median of 29 days. The order of auditory presentation was randomized across birds. The mean time between consecutive approaches within a day was 6 min (median = 5 min; minimum = 2 min; and maximum = 24 min).

For analyses, we used a mixed linear regression model (in JMP Pro 15, SAS Institute) with either FID or distance moved (log transformed) as the dependent variables, with factors being the relative velocity (the rate at which the recorded object type might be expected to be approaching: faster, intermediate or slower), relative loudness within an object-type category (see Table 1 for how relative loudness is calculated), the starting distance and the sequence of approach within a day. Bird ID was entered as a random variable. Model error structure assumed independence and a normal distribution. We fitted linear regressions (in Statview 5.1, SAS Institute) of the response of birds when approached relative to decibel levels of the cues (to test for the effect of loudness independent of object type) and their distance from cover (i.e., birds in more open areas may feel at greater risk).

RESULTS

The full results from the mixed linear regression model are given in the Supplemental Data, Table S1. For FID, all the fixed factors were significant (velocity, $P < 0.0001$; loudness, $P = 0.0045$; starting distance, $P < 0.0001$; and trial sequence, $P = 0.0024$). None of the higher order interactions were significant. Thus, birds

increased their FIDs with the expected velocity of the sound being played, the loudness of the sound within velocity categories, the starting distance, and with repeated approaches (Fig. 1).

For the distance moved away (log transformed), all the fixed factors were significant, except starting distance (velocity, $P = 0.0087$; loudness, $P = 0.0121$; starting distance, $P = 0.7280$; and trial sequence, $P = 0.0053$). The only higher order that was
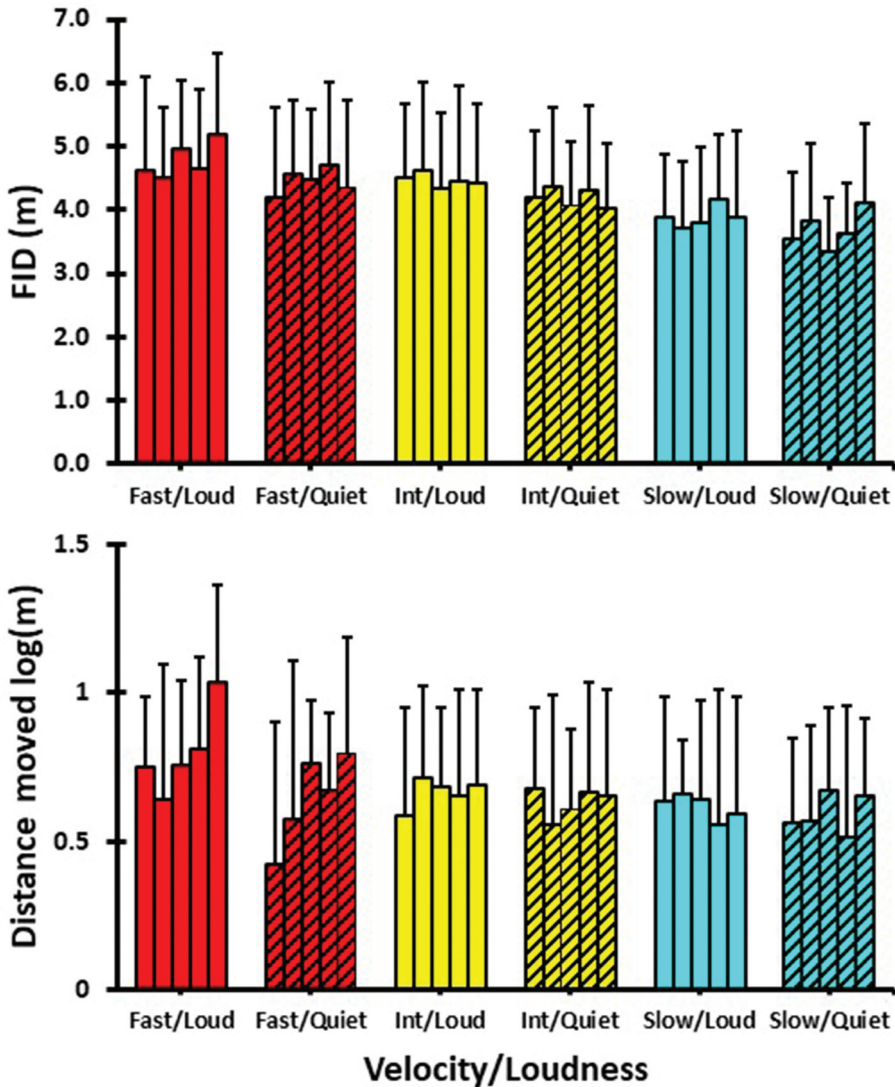

Fig. 1. — Mean distances (+ SD) for FID and movement away (log transformed). Sounds (Table 1) were of either faster, intermediate, or slower-moving objects; either moving more loudly (solid) or quietly (striped) across substrates.

significant was the interaction between velocity and sequence (P = 0.0050). Thus, birds move a greater distance in response to the expected velocity of the sound being played, the loudness of the sound within velocity categories, and to repeated approaches (Fig. 1). With repeated approaches, the distance moved particularly increased in response to the sounds of bicycles being played (Fig. 1).

The random factor of bird identity was significant for both FID (P = 0.0215) and distance moved (P = 0.0268). Thus, on an individual basis, birds do significantly differ in the distances at which they initiate flight (Supplemental Data, Fig. S1) or the distance they move. However, individual birds do not consistently habituate or sensitize across the nine different presented stimuli as all have both positive and negative slopes (Supplemental Data, Fig. S1).

We examined the effect of sound level directly and apart from the type of object that made it. For each bird, we took the mean of their FIDs or distances moved, across the five within-day approaches for each of the nine stimuli presentations, giving 12 replicates for each sound level and regressed those values against sound level (in decibels: Table 1) as the independent variable. There was no significant effect from the intrinsic loudness of the stimuli (Supplemental Data, Fig. S2. FID: $F_{1,106}$ = 1.503, R^2 = 0.0138, P = 0.2229; distance moved: $F_{1,106}$ = 0.086, R^2 < 0.0011, P = 0.7698). We regressed FID and distance moved across all approaches (n = 540) against how far away the birds were from cover. Neither response is significantly predicted by distance from cover (Supplemental Data, Fig. S3. FID: F = 2.789, R^2 = 0.0052, P = 0.0950; distance moved: F = 0.034, R^2 = 0.0003, P = 0.8545). Birds, however, were rarely far from cover with the mean distance being 0.83 m ± 0.99 SD (range = 0.25–8.00 m; median distance = 0.50 m). When they moved, it was most often not to the nearest cover (Supplemental Data, Fig. S4).

<div align="center">DISCUSSION</div>

In one urban population of juncos, we found that birds respond to the usual "meaning" of the particular sounds that an object may make. Juncos have greater FIDs and move away further when exposed to the stereotypical sounds of expectedly faster objects (bicycles), than to sounds of more moderate velocity (skateboards and scooters), or people walking at even slower velocities. Within a sound type, birds would move sooner and further away when the sound was louder (e.g., a bicycle riding over rough terrain rather than smooth, Fig. 1). Intriguingly, this is not a response to the intrinsic loudness of these sounds across object categories. For example, bicycles were among the quietest stimuli (Table 1), but elicited the significantly greatest FIDs than louder skateboards and scooters. This lack of an absolute loudness effect differs from the responses by hoatzins (*Opisthocomus hoazin*) which are more reactive when approached by tourists engaging in conversation than if they are silent (Karp & Root 2009). This study, however, approached hoatzins living in otherwise undisturbed habitat and therefore encountering humans much less often than urban-dwelling birds do. Juncos did exhibit a common pattern of FIDs positively correlating to how far away an approach was begun (Samia et al. 2017; Tätte et al. 2018), but starting distance did not affect how far they moved. Finally, in response to being repeatedly approached multiple times in a short period of time, birds increased both FID and distance moved, with largest effects being responses to bicycles (Fig. 1).

It is interesting that the juncos responded appropriately to auditory cues that lacked the usually associated visual cues. Birds always saw a human walking but heard something else that moves as fast or faster. Ample evidence shows urban birds do respond to anthropogenic visual cues, such as variation in the risk approaching humans may present (Partecke et al. 2006; Wood & Yezerinac 2006; Møller 2008; Mikula 2014; Battle et al. 2016). In this experiment, however, the auditory cue produced effects in the absence of the normally associated visual cue. Future work could probe the mechanisms of the decision-making process when the absence of an expected cue presents a mixed message. This would further test the hypothesis that the cue indicating the greatest need to quickly respond takes precedence (Munoz & Blumstein 2012).

Birds living in cities encounter a variety of novel objects that move at differing velocities and therefore may pose varying collision risks. In a multispecies study of Australian birds in urban parks, the 12 most sampled species all exhibited greater FIDs towards approaches on bicycles than approaches on foot, with the difference being significantly greater in four of the species (Bernard et al. 2018). This differs from an earlier study (McLeod et al. 2013) where vehicles could generally get closer to waterbirds than people walking. This difference may due to the species being tested and in locations of urban parks versus an access-restricted area; where vehicles are rare, novel objects usually moving at low and careful velocities (Bernard et al. 2018). Birds living in cities have ample opportunity to learn about the risks that approaching objects of anthropogenic origin can pose.

These results do come with some caveats that have implications for future research. One is the generality of the observed phenomenon. Birds at this university campus commonly encountered each of the test stimuli on an almost daily basis. Other urban areas are likely to have a different set of anthropogenic objects, with differing encounter rates and associated sounds. The question remains if the UCLA velocity-related cues are so distinctive that they are uniquely learnable. Thus, we cannot say the observed categorization of approaches by their sound would occur across all urban settings. Furthermore, the cues that sounds provide may be very different across urban and non-urban ecosystems. Fundamentally, a common risk an urban bird faces is to be hit by the approaching object or person, which is almost always unintentional. This may explain why the distance a bird moves, is not related to how far away it is from cover. The movement seems more akin to getting out of the way to avoid injury (Blumstein 1998), rather than fleeing to a protected location. In contrast, the mortality from an encounter in a non-urban setting is much more likely to reflect a predation attempt. Given this would be intentional on the part of the predator, one would expect a silent as possible approach. From an evolutionary standpoint, therefore, juncos might be expected to be warier of quietly approaching objects.

Finally, this experiment does not address if the behavior of the UCLA juncos reflects genetic differentiation from or behavioral plasticity within the ancestral non-urban population. One likely factor to their success is an ability to adjust appropriately to human activity. For example, urban juncos allow humans to get significantly closer before fleeing (Atwell et al. 2012). Some traits, such as aggression against conspecifics and declines in the whiteness of tail feathers, appear to be heritable and have changed so rapidly that it strongly suggests a response to selection pressures from urban environments (Yeh 2004; Atwell et al. 2012; Carrete & Tella 2013; Carrete et al. 2016), while others traits, such as parental feeding rates, are less clear as to the effects of genetic drift versus selection (Yeh 2004; Yeh & Price 2004; Newman et al. 2006). Thus, future work can focus on the genetic variation or inherent plasticity that allows birds to learn, categorize, and respond appropriately to urban sounds. The ability to do so may be one of the key characteristics that allows dark-eyed juncos to prosper in urban southern California.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

SUPPLEMENTAL DATA

Supplemental data for this article can be accessed at https://doi.org/10.1080/03949370.2021.2024263

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