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Abstract: Aircraft collisions with wildlife (primarily birds) are costly in terms of injury or loss of human life, loss of the animals involved, damage to property and business, and the use of lethal control of wildlife at airports worldwide. One potential nonlethal technique to reduce bird–aircraft collisions—pulsed white and wavelength-specific aircraft-mounted light—has been considered for nearly 3 decades, but the efficacy of the technique has not been evaluated quantitatively. We tested the hypothesis that during daylight, captive birds exposed to an approaching ground-based vehicle exhibiting pulsing 250-W white aircraft landing lights would initiate avoidance behavior more quickly than birds experiencing an oncoming vehicle with nonpulsing (steady) or no lights (control). In experiments involving captive brown-headed cowbirds (*Molothrus ater*), Canada geese (*Branta canadensis*), European starlings (*Sturnis vulgaris*), herring gulls (*Larus argentatus*), and mourning doves (*Zenaida macroura*), only cowbirds exhibited a response to the landing lights, but not consistently. Specifically, cowbird groups (9 groups/treatment, 6 birds/group) responded more quickly to pulse versus control treatments, equating to a greater distance ($\bar{x} \pm$ SE) of the approaching vehicle from mid-cage per reacting bird (control: 35.8 ± 9.7 m, pulse: 50.5 ± 10.9 m; $P = 0.015$). However, in a subsequent experiment involving the exposure of cowbirds to control, pulse, and steady-light treatments, we observed no difference in response among treatment groups. Although 250-W white landing lights pulsed at 45 cycles/min influenced behavior of captive birds in response to an oncoming ground-based vehicle, the avoidance response was inconsistent across experiments with cowbirds, and we observed little or no avoidance behavior in experiments with other species. We suggest that further research is needed to investigate avian response to specific light wavelengths and pulse frequencies.

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Key words: aircraft landing lights, avoidance behavior, bird strike, pulse frequency, wavelength.

From 1990 through 2002, 46,514 wildlife collisions with aircraft (97% involving birds) were reported to the U.S. Federal Aviation Administration (FAA); these incidents cost the civil aviation industry in the United States an estimated $489 million in direct monetary and associated costs annually (Cleary et al. 2003). Cleary et al. (2003) noted that approximately 93% of reported aircraft down time resulting from known-species collisions of birds with aircraft (total = 159,504 hr) for the 13-year period comprised waterfowl (Anatidae; 32.4%), raptors (Falconiformes; 30.0%), gulls (Laridae; 20.9%), doves (Columbidae; 7.7%), blackbirds (Icteridae; 0.8%), and European starlings (0.5%). Moreover, many bird–aircraft collisions (hereafter referred to as bird strikes) involve multiple birds in a single incident (Dolbeer et al. 2000, Cleary et al. 2003). For example, from 1990 through 2002, at least 294 bird strikes in the United States that caused substantial damage to aircraft involved species with average body masses >1.8 kg; 30% of these incidents involved multiple strikes to the same aircraft (Dolbeer and Eschenfelder 2003). Overall, bird strikes cost the commercial aviation industry worldwide an estimated $1.28 billion annually (US$), pose an obvious and substantial safety threat (Allan and Orosz 2001), represent a loss of birds in each incident, and necessitate management strategies at airports that include lethal control (Dolbeer et al. 1993).

Strategies and techniques for controlling wildlife on airports and in the immediate airspace are numerous and vary in effectiveness depending on habitat, species, aircraft movements, public attitudes regarding the problem species and control methodologies, cost, and integration of techniques (Dolbeer et al. 1993, Cleary and Dolbeer 1999). Use of aircraft-mounted light (via variations in pulse frequency of white and wavelength-specific light) has been considered for nearly 3 decades as a possible means of increasing visibility of aircraft to birds and thereby stimulating an avoidance response (Lustick 1973, Larkin et al. 1975, Blokpoel 1976, Thorpe 1977) . For example, in an evaluation of 313 bird strikes to United Kingdom commercial aircraft during 1976, Thor-

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pe (1977) found that 73% of strikes during daylight hours occurred during 50% of the movements when lights likely were not in use. Shima (1988) reported a possible advantage of engine spinner markings (which produce reflected light contrasting with ambient light) in reducing bird strikes to All-Nippon Airways aircraft.

Notably, Lyne et al. (1998) reported that birds killed as a result of striking aircraft showed primarily ventral injuries, indicating that avoidance behavior was initiated, but too late to avoid the aircraft. Further, work by Kelly et al. (1999) on behavioral responses of birds to aircraft corroborated findings by Lyne et al. (1998); birds startled by the presence of a moving aircraft, generally would bank and momentarily expose their ventral surface to the aircraft. Despite these anecdotal data suggesting that birds might not sense aircraft approach in time to avoid collision, no quantitative research (i.e., study designs comprising adequate controls and replication) has been conducted to evaluate means of increasing avian reaction distance in response to an approaching vehicle, such as the effects of vehicle-mounted lighting.

We quantified the effectiveness of pulsing white aircraft landing lights, controlled by the Precise Flight, Inc. (Bend, Oregon, USA), Pulselite™ system, in stimulating avoidance behavior in captive birds. The Pulselite™ system is an early-recognition lighting system that allows an aircraft pilot to pulse the landing, taxi, or forward-facing recognition lights (approx 45 cycles/min), thereby increasing the visibility of aircraft to air traffic controllers and other pilots.

METHODS

Bird Capture and Maintenance

We selected brown-headed cowbirds, Canada geese, European starlings, herring gulls, and mourning doves as species models based on species-specific frequency of strikes to aircraft (Dolbeer et al. 2000, Cleary et al. 2003) and availability. We captured brown-headed cowbirds (May 1999, Apr and May 2000) and European starlings (Sep 2001) in decoy traps in Erie County, Ohio, USA, then held the birds in 2.4 × 2.4 × 1.8-m cages in an outdoor aviary (Woronecki et al. 1988). We fed cowbirds millet and starlings a protein-based feed (e.g., Master Mix Gamebird Food, Ag Processing, Inc., Omaha, Nebraska, USA). All birds received grit and water ad libitum. Our capture and maintenance procedures for the cowbirds and starlings follow those of prior behavioral research with these same species (Dolbeer et al. 1998, Blackwell et al. 2002).

We captured Canada geese of undetermined sex during molt (20 Jun 2000) in northern Ohio. We transported the birds to a 0.4-ha fenced holding area in Erie County, Ohio, that contained grass, shade, and approximately 20 m^2 of an adjacent 2-ha pond. We cut the primary flight feathers from 1 wing before releasing the geese into the holding area (and periodically thereafter as needed). The cutting of the primary flight feathers rendered the geese flightless, but the birds were still capable of responding to an approaching vehicle via running attempts to become airborne. Prior behavioral research with Canada geese involved similar maintenance procedures, including the cutting of primary flight feathers (Dolbeer et al.1998; Blackwell et al. 1999, 2002). Whole-kernel corn and poultry pellets were provided to the geese as food supplements.

We captured herring gulls of undetermined sex during May 2001 at a breeding colony in Sandusky Bay on Lake Erie, in Erie County, Ohio, by using walk-in traps placed over nests. Gulls were held in a 3.6 × 8.5 × 2.4-m outside flight cage and supplied with water and whole rainbow smelts (*Omerus mordax*). The birds were not used in an experiment until they fed readily (approx 0.45 kg/bird/day), at least 9 days post-capture.

We used walk-in traps and rocket nets (Schemnitz 1994) to capture mourning doves in Erie County, Ohio, during August 2001. Doves were then held in 2.4 × 2.4 × 1.8-m cages in an outdoor aviary (Woronecki et al. 1988) and provided pigeon feed, grit, and water ad libitum. The birds were maintained in captivity for approximately 2 weeks prior to use.

Experimental Design

We conducted our experiments for each species separately and stratified relative to light and weather conditions during each day of an experiment. Specifically, we randomly selected treatment order (i.e., control, pulse, or steady) for tests conducted during mornings and afternoons. During each morning and afternoon session, we completed couplets (e.g., an equal number of control vs. pulse groups) or, when including a steady treatment, triplets of treatment groups under similar light and climatic conditions. However, because of varying wind and ambient light conditions within the experimental area, we could not replicate under completely homogeneous environmental conditions.

Wind and ambient light were therefore uncontrolled variables. In addition, because of the equipment and space requirements, we exposed species groups to treatments 1 group at a time. Within species, each group represented an experimental unit.

Each passerine group was held (at testing) in a 2.3 × 2.3 × 1.9-m flight cage (fitted with a 2.3-m long × 0.15-m high perch) positioned in grass approximately 0.15 m from the edge of a road closed to traffic but used for the test vehicle approach (Fig. 1). We maintained the same cage distance from the road for all experiments. We held doves in the same 2.3 × 2.3 × 1.9-m flight cage, but the cage was positioned on fine gravel and without a perch. Geese were held in a funnel-shaped pen area 1.4-m tall × 2.4-m wide over a length of 2.6 m, then progressively narrowing to a width of 0.5 m over a length of 2.7 m opposite the direction of the oncoming vehicle. Gulls were held in a funnel-shaped cage 1.6-m tall with mesh cover. The cage was 2.3-m wide over a length of 2.4 m, and then progressively narrowed over a length of 2.4 m to a width of 1.3 m. We intended the funnel shape to concentrate birds in the wide end of the holding area proximate to the oncoming vehicle, thus allowing space for reaction.

We exposed experimental groups of each species to a half-ton pickup truck fitted with the Pulselite™ system and 2 250-W aircraft General Electric sealed-beam tungsten landing lights mounted 3.6 m apart, 1.8 m above ground level, and directed parallel to the vehicle's approach to the holding area (Fig. 1). We repeated the vehicle approach 3 times per species experimental group to allow for possible habituation to the respective treatment (e.g., Conomy et al. 1998*a*,*b*) as well as potential behavioral effects caused by changing (i.e., uncontrolled) environmental factors. The time interval ($\bar{x}$ ± SE) between each iteration of the vehicle's approach per species group was 5.6 ± 1.7 min.

We used either of 2 treatment scenarios: (1) control (lights off) versus pulse (i.e., the Pulselite™ system operating and the 250-W landing lights pulsing alternately at 45 cycles/min), and (2) control, pulse, or steady lights (i.e., the 250-W lights illuminated, but not pulsing). For each group (i.e., control, pulse, or steady), the vehicle approached from a distance of 1.6 km at a consistent speed of 33.5 m/sec. Each test group was acclimated to the test cage (at least 15 min) prior to beginning vehicle runs. In addition, all test groups (5–10 replicate species groups/treatment) comprised experimentally naive birds.

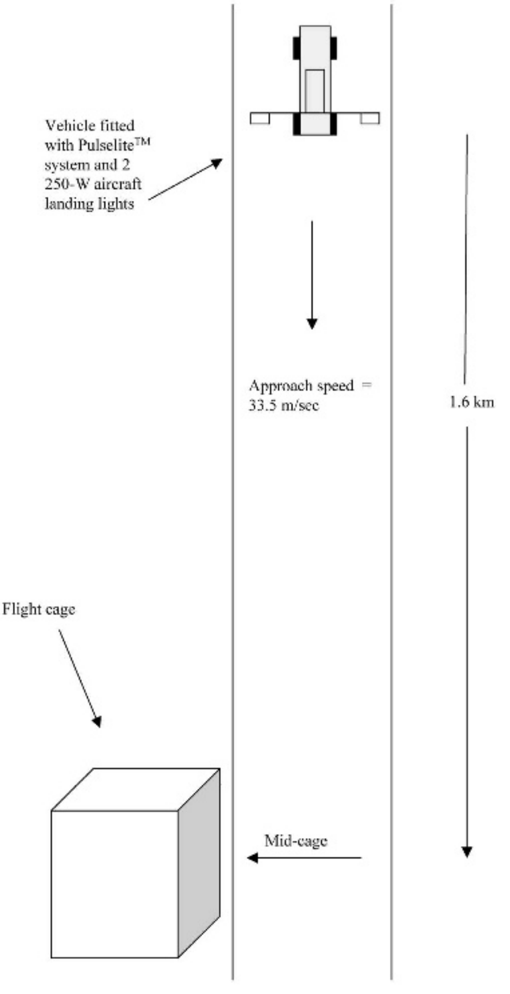

Fig. 1. Diagram reflecting the approach of a vehicle fitted with the Pulselite™ system and 2 250-W aircraft landing lights mounted 3.6 m apart, 1.8 m aboveground level, and directed parallel to the vehicle's approach to the holding area in experiments with brown-headed cowbird, Canada goose, European starling, herring gulls, and mourning dove groups exposed to either of 2 treatment scenarios: (1) control (no lights) versus pulse (i.e., the Pulselite™ system operating and the 250-W landing lights pulsing alternately at 45 cycles/min), and (2) control versus pulse, and steady lights (i.e., the 250-W lights illuminated, but not pulsing). The experiments were conducted in Erie County, Ohio, USA, during May–Sep 2000 and Apr–Oct 2001.

We measured ambient illumination for each replication per group using an INS DX-100 Digital Lux meter (INS Enterprise Company, Ltd., Taipei, Taiwan, Republic of China) and recorded wind conditions relative to the Beaufort scale. The Lux (lx) measurements provided only an index of luminous intensity, representing energy flux per-unit area of the receiving device (reported as descriptive statistics only). Similarly, because wind conditions varied over the 1.6-km approach, Beaufort numbers provided only an index of those conditions within and between groups.

Also, we used a Sony (Park Ridge, New Jersey, USA) Digital (360X Digital Zoom, Digital 8 System) Handycam TRV103 (positioned approx 20 m from the test area) to film group responses to the approaching vehicle. We recorded the amount of time required for each individual in a group to react prior to the vehicle passing mid-cage. We defined a response to the approaching vehicle as an activity (e.g., flight) that could propel the bird away from the vehicle or road, and one that was subsequently continued until the vehicle passed mid-cage. We calculated time (sec) from an individual's initial reaction to the vehicle passing mid-cage, based on the camera recording 60 frames/sec, as:

No. of frames from initial reaction to vehicle passing mid-cage/(60 frames/sec).

Based on the initial reaction times per individual, we calculated the mean distance of the vehicle to mid-cage per initial reaction of each individual (mean reaction distance) and time between the first and last reaction (group response time). Mean values for each response variable were obtained from the 3 iterations per group. We evaluated the data for normality, then used a 1-way analysis of variance (ANOVA) comprising treatment (i.e., control, pulse, or steady) to evaluate mean reaction distance within species (SAS Institute 2001). Day and a day-by-treatment interaction were evaluated as random effects. We report descriptive statistics for group response time because the variable is a component in the calculation of mean reaction distance. In general, one would expect a greater mean reaction distance to be associated with a shorter flock response time. In addition, we report descriptive statistics for the number of birds reacting per treatment group.

Experiments

Cowbirds.—We conducted our first experiment with cowbirds between 0930 and 1430 hr from 17 through 23 May 2000. We randomly assigned 20 groups of cowbirds (6 birds/group [as per Dolbeer et al. 1998, Blackwell et al. 2002]) to either control or pulse treatments (10 groups/treatment; the steady option was not functional at the time of the experiment). Our group size (for cowbirds as wells as for starlings and doves) reflected an effort to compensate for individual variability in reactions to treatments while not exasperating our ability to discern the movements of individuals on the video (see also the effect of group size in Woronecki et al. 1988). Eight cowbird groups were randomly selected for testing on day 1, followed by 4 and 8 groups for days 2 and 3, respectively.

We repeated the 2000 experiment during April and May 2001, but added a steady treatment. Cowbirds were randomly assigned to the 3 treatment groups (6 groups/treatment, 6 birds/group). We began the experiment on 18 April and completed 4 groups per treatment by 19 April. The availability of cowbirds prevented test runs for the next 2 groups per treatment until 21 and 22 May 2001. Vehicle runs were conducted between 0900 and 1445 hr.

Geese.—We conducted our experiment with geese between 0830 and 1230 hr on 31 August and 1 September 2000. Because of our sample size ($n = 36$ birds), we restricted our tests to control versus pulse treatment (6 groups/treatment, 3 birds/group). However, prior behavioral research involving 4 geese per group yielded detectable differences between treatments in experiments with both foraging (Blackwell et al. 1999) and visual repellents (Blackwell et al. 2002)

Gulls.—As with our experiment with geese, sample size again prevented a 3-treatment scenario. Therefore, we exposed 20 gulls to control and pulse treatments (5 groups/treatment, 2 birds/group) between 0900 and 1500 hr from 23 to 25 May 2001.

Doves.—We exposed 15 groups of doves (5 groups/treatment, 3 birds/group) to control, pulse, and steady treatments over 4 days between 23 and 29 August 2001. Again, our group size was similar to work evaluating rock dove (*Columba livia*; 4 birds/group) reaction to a visual repellent (Blackwell et al. 2002). We conducted the experiment between 0800 and 1430 hr.

Starlings.—We exposed 21 groups of starlings (7 groups/treatment, 6 birds/group [group size as per Blackwell et al. 2002]) to control, pulse, and steady treatments over 3 days from 15 through 18 October 2001. We conducted the experiment between 0800 and 1500 hr.

RESULTS

Cowbirds

In our 2000 experiment with cowbirds, birds escaped from 2 groups during testing (leaving group sizes of 4 and 5 birds, respectively); we subsequently adjusted group size relative to the standard of 6 individuals per group for calculation of number of birds responding. In addition, we note that 2 groups, representing a treatment and control group couplet on day 3 of the experiment, likely were affected by the arrival of a sudden low-pressure system moving through the area. Consequently, the pulse treatment group of the couplet experienced sudden wind conditions (Beaufort-5 [approx 30–38 km/hr]) that exceeded those of any other replication of the experiment. During this period, we observed that the birds subsequently moved to the ground and remained low in the grass. In contrast, the control group of the couplet experienced progressively heavy rains during the 3 iterations of the vehicle approach. We were unable to replicate an additional control and treatment group during a similar weather event that would maintain an aspect of homogeneity in experimental conditions for the treatment and control couplet. Therefore, we removed the 2 groups from the analysis (i.e., leaving 18 groups).

Ambient illumination was similar between treatment groups, differing by 12.2% ($\bar{x} \pm$ SE control: 33,500 ± 21,884 lx, range = 9,733–73,733 lx; pulse: 38,180 ± 26,336 lx; range = 7,867–76,700 lx). Mean reaction distance differed between treatments (Table 1); flock response times ($\bar{x} \pm$ SE) differed by a factor of 1.7 (control: 1.1 ± 0.6 sec; pulse: 0.7 ± 0.2 sec). The response of cowbirds to the approaching vehicle was, generally, as a flock (control: 5.6 ± 0.6 birds reacting; pulse: 6.0 birds), with flight away from the vehicle.

During our 2001 experiment, mean ambient illumination was similar among treatments, differing at most by 8.8% (control: 38,033 ± 21,130 lx, range = 2,733–60,367 lx; pulse: 41,100 ± 27,927 lx, range = 3,967–78,333 lx; steady: 41,706 ± 28,156 lx, range = 4,267–79,533 lx). We found no difference among treatment groups in consistency of response (i.e., all birds reacted) or mean reaction distance ($F_{2, 6}$ = 0.4, P = 0.680; Table 1). Subsequent flock response times were similar (control: 0.8 ± 0.4 sec; pulse: 0.9 ± 0.4 sec; steady: 0.6 ± 0.4 sec).

Geese

During our goose experiment, ambient illumination between treatment groups differed by 3.7% (control: 55,911 ± 17,688 lx, range = 34,133–75,467 lx; pulse: 53,822 ± 22,422 lx, range = 15,833–82,800 lx). Geese generally showed little reaction to the approaching vehicle (control: 1.9 ± 0.8 birds reacting; pulse: 1.9 ± 0.9 birds), but when they reacted, they made running attempts to become airborne. We found no difference between treatments in mean reaction distance ($F_{1, 8}$ < 0.01, P = 0.946; Table 1). Flock response times were consistent between treatments (control: 2.2 ± 1.4 sec; pulse: 2.1 ± 1.3 sec).

Table 1. Mean reaction distance (mean distance of the vehicle to mid-cage per initial reaction of each individual) of birds to an approaching vehicle fitted with the Pulselite™ system and 2 250-W aircraft landing lights[a] mounted 3.6 m apart; Erie County, Ohio, USA, May–Sep 2000 and Apr–Oct 2001.

Species	Mean (SE) reaction distance Control	Pulse	Steady
Brown-headed cowbird[b]	35.8 (9.7)[c]	50.5 (10.9)[c]	N[d]
Brown-headed cowbird	46.2 (10.9)	44.4 (10.5)	36.5 (21.1)
Canada goose	43.0 (25.2)	44.0 (27.4)	N[d]
Herring gull	18.5 (19.5)	24.2 (27.5)	N[d]
Mourning dove	24.4 (13.9)	21.1 (6.0)	17.4 (2.0)
European starling	45.9 (28.0)	35.6 (10.1)	44.2 (6.8)

[a] Treatments comprised control (lights off) versus landing lights pulsing alternately (pulse; 45 cycles/min) or landing lights illuminated, but not pulsing (steady). Treatment groups were exposed to 3 iterations of the vehicle approaching from a distance of 1.6 km at a consistent speed of 33.5 m/sec.

[b] Experiment conducted during May 2000.

[c] Mean reaction distance differed (1-way ANOVA, α = 0.05; $F_{1, 12}$ = 8.0, P = 0.015) between treatments.

[d] N = treatment not included in the experiment.

Gulls

Ambient illumination between gull treatment groups differed by 12.1% (control: 17,460 ± 11,646 lx, range = 9,567–37,500 lx; pulse: 19,873 ± 17,184 lx, range = 10,167–50,333 lx). Responses to the approaching vehicle comprised running and immediate flight attempts. Overall, however, gulls exhibited little reaction to the vehicle (control: 0.9 ± 0.8 birds reacting; pulse: 0.7 ± 0.6 birds), and no difference was evident between treatments in mean reaction distance ($F_{1, 4}$ < 0.20, P = 0.675; Table 1). Flock response times were similar (control: 0.8 ± 0.2 sec; pulse: 1.0 ± 0.2 sec).

Doves

During our dove experiment, ambient illumination among treatments differed at most by 20% (control: 64,733 ± 10,617 lx, range = 17,833–95,367 lx; pulse: 75,287 ± 2,863 lx, range = 26,800–108,867 lx; steady: 60,213 ± 13,928 lx, range = 39,433–90,133 lx). In addition, because of camera failure, data were lost from 1 vehicle run for a single group (i.e., leaving 2 iterations for that group) exposed to the steady treatment.

Doves typically reacted by running away from the vehicle. Flight behavior appeared as a secondary reaction across groups and was not consistent within groups. However, we found no difference among groups in consistency of response (control: 2.0 ± 0.5 birds reacting; pulse: 2.3 ± 0.7 birds; steady: 2.2 ± 0.4 birds), or in mean reaction distance ($F_{2, 6}$ = 4.2, P = 0.072; Table 1). Flock response times were similar to those of cowbirds (control: 0.9 ± 0.3 sec; pulse: 0.9 ± 0.3 sec; steady: 1.0 ± 0.3 sec).

Starlings

Ambient illumination among starling treatment groups differed at most by 16.5% (control: 55,783 ± 18,472 lx, range = 28,433–72,167 lx; pulse: 49,767 ± 18,962 lx, range = 18,633–67,900 lx; steady: 46,600 ± 19,825, range = 20,300–71,633 lx). Response to the approaching vehicle was similar across treatments, and typically the birds reacted as a flock, with flight away from the vehicle (control: 5.6 ± 0.6 birds reacting; pulse: 5.4 ± 0.6 birds; steady: 5.5 ± 0.4 birds). Mean reaction distance did not differ among treatments ($F_{2, 12}$ = 0.2, P = 0.853; Table 1). Subsequent flock response times were similar among treatments (control: 1.0 ± 0.6 sec; pulse: 1.1 ± 0.4 sec; steady: 1.0 ± 0.7 sec).

DISCUSSION

Vision is a primary sensory pathway in birds (Walls 1942) and therefore critical to sufficiently understanding their ecology (Sillman 1973). Thus, attempting to increase avian awareness of aircraft by providing additional sensory input via light is a logical approach to reduce bird strikes. Unfortunately, the safety issues and logistics associated with conducting a controlled experiment involving aircraft and avian avoidance behaviors are many. However, given that 55% of bird strikes to civil aircraft (1990–2002) occurred in flight at or below 100 feet (30.5 m) aboveground level (AGL) and approximately 38% occurred while the aircraft was on the ground (Cleary et al. 2003), we contend that a ground-based vehicle is a reasonable experimental surrogate for an aircraft.

Our results indicate that pulsing landing lights on an approaching ground-based vehicle might elicit a quicker avoidance behavior in captive brown-headed cowbirds. However, the light treatments essentially had no effect on the avoidance behavior of the other species evaluated. We note further that our conclusion for brown-headed cowbirds is based on the removal of a treatment and control couplet from the analysis because of the effects of extreme and contrasting weather events. Unlike other groups in our experiments, we were unable to replicate these conditions to complete runs with both a control and treatment group under a similar weather event. Notably, our second experiment with cowbirds revealed no difference among control, pulse, and steady groups relative to mean reaction distances to the approaching vehicle.

Our experiment with starlings produced similar findings to those from the second cowbird experiment. Although flight away from the approaching vehicle was typical, starlings exhibited no difference among control, pulse, and steady groups relative to mean reaction distances to the approaching vehicle.

Results from the goose and gull experiments suggest, not surprisingly, indifference to vehicles by each species. For example, across control and pulse groups, geese reacted inconsistently (with some individuals sleeping through the vehicle run) while gulls typically stood and watched the vehicle pass. The general lack of immediate avoidance behavior by geese in response to the approaching vehicle is a reaction consistent with the species' ecology relative to predation threats (i.e., geese might delay immediate escape behavior, opting instead to observe the behaviors of potential predators; Smith et al. 1999). We note that of 608 reported Canada goose strikes by U.S. commercial airlines (1990–2002), 302 (49.6%) occurred at or below approximately 56 feet (17.1 m) AGL, with 210 (34.5%) occurring on the ground (U.S. Federal Aviation Administration's wildlife strike database, unpublished data). Also, both geese and gulls might be so conditioned to vehicles, despite light treatments, that any avoidance behavior is latent at best (e.g., see reaction of Canada geese to aircraft in Ward et al. 1999). With regard to the cutting of primary feathers on the geese, we noted that the bird's behavior was no different than that observed in wild molt-stage geese in response to ground-based vehicles; avoidance behavior commonly comprised running attempts to become airborne. However, we recognize that the known barrier of the test cage might have modified the continuance of reactions in both geese and gulls.

In contrast to the reactions of the aforementioned species, the first reaction of doves to the approaching vehicle was most often running. Still, we found no difference among groups in mean reaction distance. Again, possible indifference to vehicles might have produced an energy-efficient response (i.e., running vs. flight) to a common disturbance.

In summary, our data indicate that avoidance behaviors in response to the 250-W aircraft landing lights (pulsed at 45 cycles/min, or steady) were not, with the exception of 1 experiment, different from responses to the control. We recognize that area limitations of the test cages might have affected initiation and continuance of avoidance behavior, particularly with geese and gulls, but the avoidance responses of passerines and doves suggest otherwise. Specifically, by our definition of avoidance response, a reaction to the vehicle was one that continued until the vehicle passed mid-cage; on average at least 93% (>5 birds of 6) of passerines and 67% (2 of 3) of doves per group reacted. Further, the percentage of individuals reacting within passerine and dove groups indicates that we achieved a balance between a biologically reasonable number of individuals per species (e.g., for vigilance and individual variation in response) and reaction space within the cage. Moreover, our group sizes—with the exception of gulls—reflect experience from prior behavioral work with the same species in the context of exposure to foraging and visual repellents. Also, our experiments with geese and gulls indicate that our test cages allowed ample space for the initial reaction but the continuance of that reaction (i.e., seeking an escape route) appeared diminished. We contend therefore that with the possible exception of geese and gulls, our findings offer reasonable inference as to the potential response of free-ranging brown-headed cowbirds, European starlings, and mourning doves to 250-W aircraft landing lights on a moving aircraft.

MANAGEMENT IMPLICATIONS

Aircraft-mounted light is intended for pilot-to-pilot and aircraft-to-ground visual identification; how birds perceive and react to their environment (e.g., Endler 1990, Finger and Burkhardt 1994, Endler and Thery 1996, Hart et al. 1998) is not considered in the design of aircraft-mounted lighting systems. Our findings indicate that 250-W landing lights, mounted on a moving ground-based vehicle and pulsed at 45 cycles/min or not pulsed, elicit little to no avoidance response in European starlings, mourning doves, Canada geese, and herring gulls. However, the significant avoidance response by brown-headed cowbirds to the pulsed treatment in our first experiment indicates that the potential to increase avian visual awareness of approaching aircraft is reasonable. We contend therefore that additional research is needed to quantify the effects of ecologically important light wavelengths (i.e., spectra that are meaningful in the contexts of foraging, mate selection, predator avoidance) on avian avoidance of approaching vehicles. Currently, work is under way to produce an aircraft-mounted lighting system that will encompass specific wavelengths and pulse frequencies so as to facilitate visual identification between aircraft and aircraft-to-ground (e.g., by use of infrared), as well as stimulate avian avoidance behavior (Philiben and Blackwell 2002).

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