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Comparison of fatal bird injuries from collisions with towers and windows

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ABSTRACT. Birds killed by colliding with towers and windows were studied to describe the type and extent of injuries and, more precisely, to suggest the actual cause of death. A total of 502 specimens (247 tower kills, 255 window kills) were dissected, radiographed, and examined. Tower and window collision categories were further subdivided to consider age (subadult versus adult) and weight (<39 g, sparrow-size or smaller, versus > 39 g, cardinal size or larger) differences in injury and differential vulnerability. Injuries were classified as superficial, subdermal, or skeletal fractures. Comparisons of injuries between tower- and window-killed specimens indicate that the consequences of these two types of collisions are similar. Subdermal injuries were more severe in tower kills than in window kills. Subadults experienced more severe subdermal injuries than adult tower and window casualties. Among window kills, larger birds had more severe subdermal injuries than smaller birds. Collision victims may show blood or fluid in the mouth or nose cavities (30–60%), almost all have subdermal intracranial hemorrhaging (98–99%), and most lack any evidence of skeletal fractures (82–91%). Histological examination of the brain of two specimens revealed blood pools in the cerebrum and cerebellum. The extravascular bleeding in and around the brain is probably the actual cause of death in collision fatalities. Treatment to reduce brain edema if administered within 6–8 h shortly after impact can save some strike casualties.

SINOPSIS. **Comparación de heridas fatales producidas por el choque contra torres o ventanas**
Se estudiaron aves que perecieron a causa de choques con torres o ventanas para describir el tipo y extensión de las heridas y sugerir. con precisión la causa de la muerte. Un total de 502 cadáveres (247 que chocaron con torres y 255 que chocaron con ventanas) fueron disectados, radiografiados y examinados. Las choques con torres y ventanas fueron posteriormente subdivididos para considera la edad (adulto vs. juvenil), peso (≤39 g, tamaño de un pinzón o más pequeño vs. > 39 g. o el tamaño de un cardenal o mayor), diferencias en las heridas y vulnerabilidad diferencial. Las heridas fueron clasificadas como superficiales, subdermales o fracturas esqueletales. La comparación de las heridas en los cadáveres causadas por choques con torres o ventanas indicaron que las consecuencias de estos dos tipos de colisiones son similares. Las heridas subdermales fueron más severas en aves que chocaron con torres que con ventanas. Los subadultos experimentaron heridas subdermales más severas que los adultos tanto en choques con torres como con ventanas. Se encontraron además heridas subdermales más severas en aves grandes que en pequeñas, entre aquellas que chocaron con ventanas. Las víctimas de los choques mostraron sangre o fluidos en la boca o en la cavidad nasal (30–60%), y casi todas mostraron hemorragias subdermales intracraniales (98–99%); la mayoría no mostró evidencia de fracturas esqueletales (82–91%). El examen histológico del cerebro de dos cadáveres revelo sangre en el cerebro y el cerebelo. El sangramiento extravascular y alrededor del cerebro probablemente fue la causa de la muerte de las aves que chocaron. Se pueden salvar algunas de las aves que han sufrido colisiones aplicando un tratamiento para reducir la edema cerebral entre las primeras 6–8 h. luego de ocurrido el choque.

Key words: collision injuries, cooling towers, glass, tower kills, window kills

Avian collision casualties are receiving increased attention for their effect on certain species and bird populations in general (Klem 1989, 1991; Shire et al. 2000; Erikson et al. 2001). Where annual avian mortality at solid elevated structures is estimated in the millions of individuals, the kill at plate glass, from small garage panes to windows consisting of entire walls of multistory buildings, is in the hundreds of millions for the U.S alone (Banks 1979; Klem 1990a, 1991; Dunn 1993). The injuries, cause of death, and recuperation of window kills have been reviewed and described to an effective but limited degree (Klem 1990b). Here we quantitatively document and compare fatal injuries resulting from collisions with a concrete elevated nuclear power plant cooling tower and with plate glass windows, and provide a more specific explanation of cause of death. The findings provide additional mea-

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sures to aid rehabilitators, veterinary professionals, and others attempting to diagnose and treat avian collision casualties at impact sources.

METHODS

Data were obtained from known tower and window collision specimens cataloged in the Natural History Museum, Department of Biology, Muhlenberg College, Allentown, Pennsylvania. Tower kills were collected after striking and falling to the base of cooling towers at the nuclear power plant in Limerick, Montgomery County, Pennsylvania in 1979 and 1980. Window kills were collected from several commercial and residential buildings in and around Carbondale, Jackson County, Illinois, and Allentown, Lehigh County, Pennsylvania, from 1971 to 1980. Tower kills occurred during nocturnal passage and were discovered as much as eight hours after death. Window kills occurred during daylight and were discovered immediately or within one to two hours after death. Detailed examinations were conducted to determine superficial, subdermal, and skeletal injuries in the head and neck regions of 255 tower kills of 22 species and 247 window kills of 58 species. Histological preparations from a window-killed Sharp-shinned Hawk (*Accipiter striatus*) and an American Robin (*Turdus migratorius*) were studied to determine internal soft tissue injuries to the brain. Only head and neck injuries were examined because previous work revealed no discernible injuries to other parts of the body (Klem 1990b).

Superficial injuries were ranked according to severity and consisted of the presence or absence of blood or fluid in the mouth, nasal cavity, or both. After removing the skin from the head, subdermal injuries were recorded by drawing the extent of visible blood pooling within the skull. Sagittal halves of the skull of each specimen were compared to determine if blood pooling was a consequence of typical postmortem change (Harrison and Harrison 1986). If blood pooling was symmetrical, noncollision bleeding was judged to have occurred; asymmetrical blood pooling was judged the result of collision injury. Additionally, impact injuries were recorded if blood pooling was so extensive that it obscured the double layer of cranial bone in adult specimens. Six subdermal injury categories were used to record the severity of impact based on the extent of blood pooling: (1) none, (2) $<$25%, (3) 26 $<$ 50%, (4) 51 $<$ 75%, (5) 76 $<$ 99%, and (6) completely covered. Skeletal fractures were recorded by detailed analysis of radiographs; four aspects of each specimen were taken (dorsal and ventral, left and right lateral). A Vector brand Picker International X-ray Unit at the Allentown Osteopathic Hospital, Allentown, Pennsylvania was used with the following unit parameters: 40 kilovolts, 75 milliamps, 15 milliamp-s, and A9% anode; x-ray tube focal spot was extended to 94 cm to maximize definition and detail (Harrison and Harrison 1986). Specimens were placed directly on the film cassette to obtain the sharpest image. Kodak MIN-R film was used in a Kodak X-O-Matic cassette with single lanex fine screen, and developed using Kodak MGAW processor with a 90-s cycle.

The two window-killed histological specimens were preserved *in toto* immediately after death by immersion in Tellyesniczky's AAF fixative for 24 h, and then stored in 70% ethanol (Lillie 1965). Their brains were removed, embedded in paraffin, cut sagittally at 7 microns, and stained with hematoxylin and eosin using standard procedures (Lillie 1965; Humason 1979). Each serial slide was examined using a light microscope and photomicrographs were taken with an Olympus Vanox microscope.

All specimens were cataloged with a unique number, weighed, sexed by plumage and gonadal examination, and aged by plumage and the extent of skull pneumatization for passerines (Miller 1946). Anatomical terminology follows Baumel et al. (1993).

Chi-square tests of independence were used to compare superficial and subdermal injuries between tower and window casualties, subadult and adult age classes within the separate tower- and window-kill samples and select tower-killed species having sufficient samples sizes, and window-killed weight classes consisting of $0 \leq 39$ g (hummingbirds to sparrows) and $>$39 g (cardinal to bobwhite; SPSS 2002). All comparisons based on 2 $\times$ 2 contingency tables were evaluated after applying a correction for continuity (Siegel 1956).

RESULTS

Superficial injuries differed between tower and window casualties ($\chi^2_3 = 50.8$, $P < 0.001$,

Table 1. Superficial injuries of tower and window collision bird fatalities.

		Presence of blood or fluid			
		None	Mouth cavity	Nasal cavity	Mouth and nose
Category	*N*	*N* (%)	*N* (%)	*N* (%)	*N* (%)
Tower					
Total	247	174 (70)	71 (29)	2 (1)	0 (0)
Age					
Subadult	167	113 (68)	53 (32)	1 (1)	0 (0)
Adult	72	54 (75)	17 (24)	1 (1)	0 (0)
Window					
Total	255	101 (40)	143 (56)	5 (2)	6 (2)
Age					
Subadult	97	43 (44)	50 (52)	3 (3)	1 (1)
Adult	121	42 (35)	73 (60)	2 (2)	4 (3)
Weight class					
≤39 g	168	68 (41)	93 (55)	4 (2)	3 (2)
>39 g	87	33 (38)	50 (58)	1 (1)	3 (3)

Table 1). Differences were most evident in the amount of detectable blood and fluid in the mouth cavity: undetected in 70% of tower-kills, present in 56% of window-kills. There were no differences in superficial injuries between subadult and adult tower (χ^2_2 = 1.9, *P* = 0.39, Table 1) or window (χ^2_3 = 3.7, *P* = 0.29, Table 1) fatalities. Similarly, there were no superficial differences between subadult and adult tower-killed Red-eyed Vireo (*Vireo olivaceus*, subadult, 40% without blood in mouth, 54% with blood; adult, 64% without blood, 36% with blood; *N* = 48; χ^2_1 = 0.5, *P* = 0.49) and Magnolia Warbler (*Dendroica magnolia*, subadult, 62% without blood, 36% with blood; adult, 83% without blood, 17% with blood; *N* = 28; χ^2_1 = 0.6, *P* = 0.43). Comparison of window-killed weight classes revealed no differences in superficial injuries between small (≤39 g) and large (>39 g) birds (χ^2_3 = 1.3, *P* = 0.74, Table 1).

Subdermal injuries differed between tower and window casualties (χ^2_5 = 13.4, *P* = 0.020, Table 2). Tower-killed birds had proportionately greater amounts of intracranial blood pooling (>50%) than window-killed birds. Subadults differed from adults in having more blood pooling in both tower (χ^2_5 = 30.7, *P* < 0.001, Table 2) and window (χ^2_5 = 16.4, *P* = 0.006, Table 2) fatalities. There were no subdermal injury differences between subadult and adult tower-killed Red-eyed Vireo (subadult, 31% ≤ 50% intracranial blood pooling, 69% > 50% blood pooling; adult, 36% ≤ 50% blood pooling, 64% > 50% blood pooling; *N* = 50; χ^2_1 = 0.0, *P* = 0.99), Magnolia Warbler (subadult, 56% ≤ 50% blood pooling, 44% > 50% blood pooling; adult, 85% ≤ 50% blood pooling, 15% > 50% blood pooling; *N* = 29; χ^2_1 = 1.5, *P* = 0.22), and Common Yellowthroat (*Geothlypis trichas*, subadult, 44% ≤ 50% blood pooling, 56% > 50% blood pooling; adult, 88% ≤ 50% blood pooling, 12% > 50% blood pooling; *N* = 26; χ^2_1 = 2.6, *P* = 0.11). Among window fatalities there were proportionately more low-level amounts of blood pooling in small (≤39 g) birds and proportionately more high-level amounts of blood pooling in large (>39 g) birds (χ^2_5 = 24.9, *P* = 0.001, Table 2).

Most tower and window fatalities lacked skeletal fractures, and all fractures were in the mandible-anterior skull junction where individuals most likely first contacted the glass surface (Table 4). More tower-killed adults sustained fractures than subadults, but proportionately more window-killed subadults had fractures than adults. Small (≤39 g) and large (>39 g) window-killed birds did not differ in the proportionate number of fractures. In general, the

Table 2. Subdermal injuries of tower and window collision bird fatalities.

		Percent coverage of intracranial blood pooling					
		None	≤25	26 ≤ 50	51 ≤ 75	76 ≤ 99	100
Category	*N*	*N* (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)
Tower							
Total	247	3 (1)	89 (36)	33 (13)	19 (8)	90 (36)	13 (5)
Age							
Subadult	167	0 (0)	47 (28)	19 (11)	13 (8)	76 (46)	12 (7)
Adult	72	3 (4)	36 (50)	14 (19)	6 (8)	12 (17)	1 (1)
Window							
Total	255	5 (2)	112 (44)	33 (13)	34 (13)	64 (25)	7 (3)
Age							
Subadult	97	0 (0)	34 (35)	9 (9)	17 (18)	33 (34)	4 (4)
Adult	121	5 (4)	58 (48)	19 (16)	16 (13)	22 (18)	1 (1)
Weight class							
≤39 g	168	5 (3)	88 (52)	19 (11)	17 (10)	38 (23)	1 (1)
>39 g	87	0 (0)	24 (28)	14 (16)	17 (20)	26 (30)	6 (7)

type of fracture and their proportionate occurrence were similar in tower and window casualties.

Histological study of serial sagittal sections of the window-killed Sharp-shinned Hawk and American Robin revealed impact trauma to the brain. Extensive intracranial hemorrhaging and large blood pools were present in the cerebrum and cerebellum of both specimens.

DISCUSSION

Overall, tower and window collision fatalities sustained similar superficial, subdermal, and skeletal injuries, and had the same cause of death. The differences in superficial injuries between tower and window casualties are best explained by the way specimens were discovered, collected, and recorded. Most tower kills were

Table 3. Skeletal injuries of tower and window collision bird fatalities.

		Fractures		
		None	One or more	Individuals with more than one
Category	*N*	*N* (%)	*N* (%)	*N* (%)
Tower				
Total	247	203 (82)	44 (18)	28 (11)
Age				
Subadult	167	141 (84)	26 (16)	17 (10)
Adult	72	55 (76)	17 (24)	11 (15)
Window				
Total	255	232 (91)	23 (9)	11 (4)
Age				
Subadult	97	85 (88)	12 (12)	5 (5)
Adult	121	118 (98)	3 (3)	2 (2)
Weight class				
≤39 g	168	153 (91)	15 (9)	7 (4)
>39 g	87	79 (91)	8 (9)	4 (5)

Table 4. Species and cranial fractures of tower and window collision bird fatalities.

Category	*N*	Bones fractured[a]
Tower		
Ruby-throated Hummingbird (*Archilochus colubris*)	1	os dentale
Brown Creeper (*Certhia americana*)	1	os dentale
Ruby-crowned Kinglet (*Regulus calendula*)	3	os dentale, os nasale, os maxillare, os premax-os nasale
Red-eyed Vireo	9	os dentale, os nasale, os maxillare, os palatinum
Northern Parula (*Parula americana*)	1	os dentale, os maxillare
Magnolia Warbler	5	os dentale, os nasale, os maxillare
Black-throated Blue Warbler (*Dendroica caerulescens*)	3	os dentale, os premax-os nasale
Yellow-rumped Warbler (*Dendroica coronata*)	1	os dentale
Black-throated Green Warbler (*Dendroica virens*)	1	os palatinum
Blackburnian Warbler (*Dendroica fusca*)	4	os dentale, os nasale, os maxillare, os premax-os nasale, os premax-os max
Bay-breasted Warbler (*Dendroica castanea*)	4	os dentale, os maxillare
Blackpoll Warbler (*Dendroica striata*)	1	os dentale, os premax-os nasale
Ovenbird (*Seiurus aurocapilla*)	4	os dentale, os nasale, os maxillare, os premax-os nasale
Common Yellowthroat	6	os dentale, os nasale, os maxillare, os premax-os nasale
Window		
Northern Bobwhite (*Colinus virginianus*)	2	os dentale, os palatinum
Mourning Dove (*Zenaida macroura*)	2	os dentale, os nasale, os maxillare
Tufted Titmouse (*Baeolophus bicolor*)	1	os premax-os nasale, os premax-os max
Gray-cheeked Thrush (*Catharus minimus*)	1	os dentale
Wood Thrush (*Hylocichla mustelina*)	1	os dentale
American Robin	2	os dentale, os premax-os nasale
Cedar Waxwing (*Bombycilla cedrorum*)	2	os dentale, os maxillare, os premax-os nasale
Red-eyed Vireo	1	os nasale, os maxillare
Tennessee Warbler (*Vermivora peregrina*)	3	os dentale
Blackburnian Warbler	1	os dentale
Ovenbird	2	os dentale, os nasale, os maxillare, os premax-os nasale
Canada Warbler (*Wilsonia canadensis*)	1	os dentale
Yellow-breasted Chat (*Icteria virens*)	1	os dentale
Scarlet Tanager (*Piranga rubra*)	1	os dentale, os maxillare
White-throated Sparrow (*Zonotrichia albicollis*)	1	os dentale

[a] Abbreviations: region of processus frontalis of premaxillare and processus premaxillaris of os nasale (os premax-os nasale), and region of processus maxillaris of os premaxillare and os maxillare (os premax-os max).

discovered and collected hours after impact, and the amount of blood and fluid in the mouth and nasal cavities was recorded days later when this evidence would have been more difficult to measure due to drying. By contrast, all window kills were discovered within a few hours of death, and the presence or absence of fluids in the mouth and nose was recorded immediately. Subdermal injuries measured by the amount of intracranial blood pooling was more severe in tower kills than in window kills. These differences may result from the force with which birds strike the respective concrete and glass. Migrants aloft flying at more consistent speeds may strike concrete or metal towers with greater momentum, causing greater injury than for birds near the ground flying at more variable speeds from vegetation or feeders and striking glass where the momentum is enough to be fatal but less severe. Similarly, as expected, subadults with potentially incomplete cranial development differed from adults in the amount of subdermal injury within the tower and window samples, although no intraspecific age differences were evident for three species (Red-eyed Vireo, Magnolia Warbler, Common Yellowthroat). The same skeletal fractures to the mandible and other anterior skull bones indicate that collision victims most often hit both types of structures head first.

Most tower (82%) and window (91%) fatalities experienced no skeletal fractures, and no cervical fractures were found in either the tower- or window-kill samples, further confirming that the often cited cause of death of collision victims from a "broken neck" is clearly in error. However, documenting that broken necks can occur from high speed collisions, a detailed pathology report from Tufts University Veterinary Medical Center describes an immature Peregrine Falcon (*Falco peregrinus*,) who after striking a window in Boston, Massachusetts, sustained a cervical fracture (C6), was initially paralyzed from the neck down, and succumbed to this and other complications resulting from the impact (T. French, pers. comm.). Moreover, avian window collision injuries are known for body parts other than the head and neck. The rehabilitation program at the Raptor Trust in Millington, New Jersey, has recorded coracoid displacement and fractures in window strike casualties (L. J. Soucy, Jr., pers. comm.).

Our histological examination of internal brain damage in two window-killed specimens found substantial hemorrhaging in the cerebrum and cerebellum. Blood pools were most prominent in the cerebellar white matter. Fatalities resulting from collisions are most likely the result of damage to the cerebellar communicating fibers (vital afferent and effect tracts), breakage of blood vessels and subsequent rupturing of the blood—brain barrier at several sites, complications from herniation of parts of the cerebellum and medulla through the foramen magnum, and the extensive subdural bleeding followed by intracranial edema. Symptoms exhibited by collision survivors support this conclusion (Klem 1990b); prior to death, strike casualties are often completely or intermittently non-responsive, lack balance, normal posture, or coordinated muscle action, some exhibit ipsilateral drooping eye, wing, and dilated pupil, and rapid or slow heaving respiratory movements. These internal brain injuries best explain the cause of death of collision fatalities. Those treating survivors have had some success in administering the drug dexamethasone sodium phosphate as much as six to eight hours after impact to help limit brain swelling (R. Hunsinger, pers comm.).

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