SURFACE TEXTURE DISCRIMINATION BY BATS: IMPLICATIONS FOR REDUCING BAT MORTALITY AT WIND TURBINES

By

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INTRODUCTION

Wind power is one of the fastest growing renewable energy sources and is expected to continue to increase globally (Wiser et al. 2015). Nonetheless, there are concerns over the potential threats that wind facilities pose to wildlife populations. For example, large numbers of bats are killed at wind turbines annually across North America, and just 3 species of migratory tree bats comprise 78% of these fatalities: hoary (*Lasiurus cinereus*), eastern red (*Lasiurus borealis*), and silver-haired bats (*Lasionycteris noctivagans*; Arnett et al. 2008, Arnett and Baerwald 2013). The period of peak fatality at wind turbines for these species occurs from July through September coinciding with fall migration, and it has been estimated that up to 90% of annual fatalities occur during this time (Rydell et al. 2010). Many studies have been undertaken to better understand fatality rates (e.g., Huso 2011, Strickland et al. 2011, Korner-Nievergelt et al. 2013), patterns of fatality (e.g., Arnett et al. 2008, Baerwald and Barclay 2008, Korstian et al. 2013), and the proximate causes of fatality (e.g., Baerwald et al. 2008, Horn et al. 2008, Rollins et al. 2012); however, we still do not entirely understand why bats are coming into contact with wind turbines.

Researchers have proposed 3 broad explanations for the ultimate causes of bat fatalities at wind turbines: 1) fatalities are random events that reflect local bat abundance; 2) fatalities are coincidental as wind turbines are located in close proximity to existing resources where bat activity may be concentrated; and 3) fatalities occur because bats are attracted to wind turbines (Cryan and Barclay 2009). Note that these proposed explanations are not mutually exclusive and may vary among species. Previous studies at wind facilities have shown that bats approach both rotating and non-rotating blades and investigate various parts of wind turbines, providing evidence that bats are attracted to wind turbines (Horn et al. 2008, McAlexander 2013). Three general hypotheses of attraction have been proposed: 1) bats are interested or intrigued by the sound, motion, or lights associated with wind turbines; 2) turbines provide a resource for bats (i.e., foraging, mating, or roosting sites; Kunz et al. 2007, Horn et al. 2008, Cryan et al. 2014); and 3) turbines are misperceived to provide one or more resources (Cryan and Barclay 2009, Cryan et al. 2014, McAlexander 2013).

Although additional research concerning these attraction hypotheses is still needed, several have been partially explored. For example, to date, studies have not supported the hypothesis that bats are attracted to aviation lighting on wind turbines (Bennett and Hale 2014, Horn et al. 2008, Baerwald and Barclay 2011). In contrast, observations suggest that bats pursue moving wind turbine blades, but it is still unclear as to why bats do this (Horn et al. 2008). Furthermore, the light grey color of turbine towers and blades has been shown to attract more insects than other colors; thus, the turbines could serve as a foraging resource and thereby attract insectivorous bats (Long et al. 2011). Additionally, Cryan et al. (2014) observed bat behavior on the leeward side of turbines similar to bat behavior seen at tall trees which regularly provide roosting, foraging, and mating opportunities. Therefore, there are many reasons why bats may be attracted to wind turbines.

The bat species commonly killed at wind turbines rely on a sophisticated echolocation system to navigate and locate resources such as prey items, water sources, and roost sites in low light levels (von Helversen and von Helversen 2003, Greif and Siemers 2010, Altringham 2011). Echolocating bats emit ultrasonic vocalizations in flight, and the returning echoes allow them to discern the shape, size, distance, and texture of objects (Falk et al. 2011), thereby providing them a detailed image of the surrounding environment (Altringham 2011). Several recent studies concerning echolocation, however, have demonstrated that a bat's perception of manufactured objects may be maladaptive (Greif and Siemers 2010, Russo et al. 2012, McAlexander 2013).

In a controlled setting, Greif and Siemers (2010) demonstrated that water recognition in bats is innate and that bats attempted to drink from smooth surfaces such as metal, plastic, and wood even in the presence of conflicting touch and olfactory cues. Additionally, a field experiment by Russo et al. (2012) using wild bats showed that multiple bat species attempted to drink from water troughs covered with either black or transparent Plexiglas. Moreover, these bats made consecutive drinking attempts before they left the vicinity of the water troughs, further demonstrating that bats are not able to differentiate manufactured smooth surfaces from water (Russo et al. 2012). Greif and Siemers (2010) also compared different types of surfaces and found that when ultrasonic sounds equivalent to bat echolocation calls were played towards smooth surfaces, the echoes returning from these surfaces looked similar to the echoes returning from water; however, the echoes from textured surfaces were not similar to either the smooth surfaces or water. In this same study, bats in the controlled setting did not attempt to drink from textured surfaces.

Ultrasonic playback experiments conducted by McAlexander (2013), confirmed that returning echoes from wind turbine towers, an example of a smooth manufactured surface, were similar to returning echoes from water. Night vision surveys in this study also showed wild bats coming into contact with turbine towers using the same approach and posture as bats drinking at water sources (McAlexander 2013). Together, these observations strongly suggest that bats may be approaching and making contact with wind turbine towers because they misperceive the flat, smooth surfaces to be water. If bats misperceive the smooth turbine towers to be water via echolocation, bats may attempt to drink or may make consecutive drinking attempts at turbine towers in the same way that Russo et al. (2012) observed multiple drinking attempts at covered water troughs. This misperception could ultimately increase collision risk by causing bats to spend more time within and in close proximity to the rotor swept zone (the total airspace encompassed by the moving blades) at turbine towers.

Nevertheless, if turbine tower surfaces could be texturized so that returning echoes from bat echolocation calls no longer resemble echoes returning from water, we propose that bats would potentially spend less time attempting to drink from or investigating the tower surface and therefore spend less time within the rotor swept zone. Ultimately, any reduction in time spent in the rotor swept zone by bats should lead to a reduction in collision risk with rotating blades. Therefore, identifying and creating a texture that could be put on turbine towers to obviate this misperception may represent an effective strategy to mitigate bat fatalities.

The objectives of this project were therefore to 1) determine if bats in a flight facility would attempt to drink from smooth painted surfaces similar to wind turbine towers, and 2) identify a surface texture that bats show little or no interest in approaching. To accomplish these objectives, we captured local bats (including species that are frequently killed at wind turbines) and conducted a behavioral experiment in a flight facility at Texas Christian University. We created smooth and textured surfaces of varying types and grade and recorded how these wild-caught bats behaved towards each surface. The ultimate goal of the behavioral experiment was to inform the development of a cost-effective texture coating that could be applied to existing wind turbine towers or towers in the manufacturing stage as a mitigation strategy for bat fatalities at wind farms.

METHODS

Mist netting surveys

The bats used in the behavior trials were wild-caught from local parks in and around Fort Worth, Texas, including South Z Boaz, Overton, Foster, Trinity, and Forest Parks owned by the City of Fort Worth and operated by Fort Worth Parks and Community Services, and Rocky Creek Park owned and operated by the U.S. Army Corps of Engineers (Fig. 1). Preliminary acoustic bat monitoring surveys revealed that these parks had a diverse and active bat community, including all 6 local bat species: hoary, eastern red, silver-haired, evening (*Nycticeius humeralis*), tri-colored (*Perimyotis subflavus*), and Mexican free-tailed (*Tadarida brasiliensis*) bats.

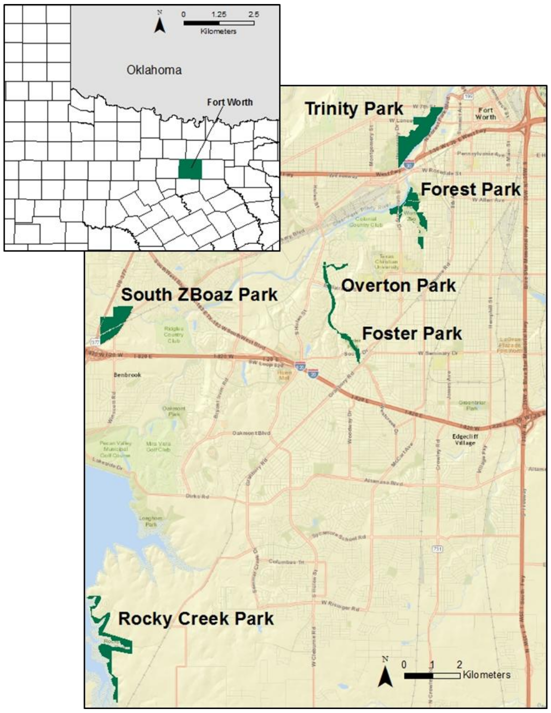


Figure 1. Locations of the parks (in green) selected for mist netting surveys in and around Fort Worth, TX.

At each park, we used mist nets to catch bats (Fig. 2). The mist nets (triple-high and single 6-18 m length monofilament nets from Avinet Inc., Dryden, NY) were set up and opened 10 minutes before dusk, weather permitting, and remained open for up to 3 hours after dusk as this represented the primary activity periods of bats (Baerwald and Barclay 2011). In order to prevent the bats from becoming accustomed to the presence of the mist nets, we surveyed a different park each night (i.e., weekly rotation). Once the nets were opened, we moved ~15-20 m away as not to disturb the bats and checked the nets every 10 minutes. Upon removal from the net, we placed bats in cloth sacks and hung them on the side of the mist nets until the surveys were completed. In the event that a bat was in the net for >5 minutes during removal, we cut the bat out of the net to ensure that bats did not spend more than 15 minutes in the net in total. In addition, bats that were identified during removal from the net to be 1) pregnant, 2) lactating, 3) carrying young, or 4) federally endangered (note that no federally endangered bats are known to currently reside in north-central Texas) were immediately taken away from the mist nets and released as quickly as possible. All personnel involved with mist netting had the rabies pre-exposure vaccination series and wore bite-proof gloves when handling bats.

Figure 2. Images of triple high mist netting set-ups.

At the end of the mist netting session or when up to 8 bats had been caught, we transported the bats to the flight facility (see below). The bats that were housed in this flight facility were only included in the behavioral trials for a limited amount of time (<4 weeks) and were then released at their site of capture.

Note that for mist netting surveys, we had an Institutional Animal Care and Use Protocol (IACUC permit #14-01) in place. An approved protocol was required by federal regulations in order to use animals in research, teaching, and testing under the Health Research Extension Act (HREA) and key amendments to the Animal Welfare Act (AWA). Furthermore, the state of Texas does not require a permit to conduct mist netting surveys, although permits were acquired to be in local parks after dusk.

Flight facility

In 2014, the flight facility was a stand-alone building approximately 8.5 m by 7.3 m by 3.3 m (Shade Tree: Rolling Hills Trading Inc., Lincoln, NE). Preliminary behavioral trials confirmed that eastern red, evening, and Mexican free-tailed bats could fly unhindered in a facility of this size. Hoary bat flight was impeded, however, as this species requires a minimum flight area of ~23 m^2 (Lollar 2010). Thus, in 2015, we moved to a larger flight facility (14.6 m by 8.5 m by 3.3 m; ClearSpan Fabric Structures, Dyersville, IA; Fig. 3) to provide sufficient room for hoary bats to maneuver.

Figure 3. Exterior view of flight facility with custom-made screen windows.

In order to effectively collect data for two experiments simultaneously (this study and Jarzombek 2016), we divided the facility into two rooms (8.5 m by 7.3 m) using a mesh partition, and when a hoary bat was caught this partition was removed (Fig. 4). To construct the partition, we used hot glue to attach 1.2 m by 3.8 m panels of Phifer charcoal fiberglass screen together. We glued the screen to the ceiling and attached the lower 1.8 m of the screen to the walls with Velcro. We used sandbags to securely seal the bottom edge of the partition. To prevent the bats from crawling into hard-to-reach crevices, we attached additional strips of fiberglass screen around the joints of the facility’s ceiling and along the base where the wall and baseboard connected to the sides and back of the facility. To prevent the bats from escaping under the front of the facility, we attached tarp to extend the length of the front wall and then used sandbags to secure this edge. Additionally, we poured sand around the interior perimeter of the flight facility to fill in any gaps between the baseboard and floor. Finally, we checked the integrity of the facility each day and used sandbags, gorilla tape, or hot glue to seal any holes that bats could use to escape.

Figure 4. Interior view of flight facility showing the mesh partition, shallow water tray in the center, and treatment surfaces covered by camouflage netting.

As we wanted the bats in the flight facility to behave as naturally as possible, conditions within the facility were kept similar to the bats' natural environment. Subsequently, no visible artificial lights were used during the drinking behavior trials, and researchers only used headlamps pre- and post-trials. Similarly, we kept the temperature and humidity within the facility similar to the conditions outside the facility, using a series of mesh-covered windows to ensure appropriate ventilation. We installed eight 0.6 m by 0.9 m and four 1.2 m by 0.9 m Phifer Brite aluminum screen windows. Additionally, we connected six 1.2 m by 30.5 m rolls of Reflectix® double reflective insulation and secured it to the portion of the facility roof that received direct sunlight. We also monitored the conditions within the facility and checked on the bats throughout the day to ensure their well-being (i.e., ensuring that bats were not dehydrated or overheating). Checks were conducted at approximately 8 am, 12 pm, and 4 pm, although additional checks were conducted in inclement weather. We placed two thermometers on the outside of the facility and an RC-5 Mini LCD USB High Accuracy Temperature Data Logger (Elitech) in the facility to record the temperature every 15 minutes. On days in which the temperature was forecasted to be above 100˚F, we turned on two 20-in HDX high-velocity floor fans that were placed directly outside of the windows to increase air circulation within the facility (Fig. 5).

Figure 5. A 20-in HDX high-velocity floor fan on concrete cinder blocks was used to circulate air throughout the flight facility.

A custom-made shallow galvanized steel water tray (2.5 m x 1 m x 1.5 cm) was centered in the room. We coated the inside of the tray with EMI5005 RTV food grade adhesive silicone sealant (EMI Supply Inc., Monroe NC) to prevent rusting and zinc leaching into the bats' drinking water. During each check, at the beginning of each survey night, and after each drinking behavior trial we ensured that the water tray was completely full. We also equipped the facility with species-specific roosting opportunities. Soft puppy carriers and carpeted cat houses were provided for cavity-dwelling species (evening, tri-colored, and Mexican free-tailed bats), and branches in tree stands were provided for tree-dwelling species (eastern red, hoary, and silver-haired bats; Fig. 6; Lollar 2010).

Figure 6. Roosting opportunities provided for the bats within the flight room.

Before we released bats into the flight facility, we recorded the age, sex, weight, and forearm length of each individual. In order to identify each individual bat while in the facility, we coated their backs with unique combinations of non-toxic pink, green, orange, blue, purple, and yellow UV florescent ECO pigments (Day-Glo Color Corp, Cleveland, OH; Fig. 7). We then used handheld ultraviolet flashlights to determine the identity of each bat in their roost sites during checks and while actively flying during the drinking behavior trials. Additionally, as a backup, we painted a unique color combination of non-toxic Piggy Paint nail polish on the bats' toes. We reapplied the ECO pigments each day and repainted their toes as needed. Note, as eastern red bats were more sensitive to handling than other species, we released them into the flight facility as soon as possible on the night of capture. We therefore measured morphometrics and gave them unique identities on the second or third night in the facility.

Figure 7. Evening bat (*Nycticeius humeralis*) marked with blue ECO pigment.

Drinking behavior trials were not conducted until the bats had acclimated to the flight facility (i.e., when the bats were observed actively flying, drinking from the water tray, and exhibiting foraging behavior). Preliminary behavioral surveys in 2014 revealed that this process took approximately 1-3 days. During acclimation nights, using Olympus Digital Voice Recorders (WS-SIOM), we described the behavior of each individual bat while it was in close proximity to the water tray. We then used these recordings to determine the baseline behavior of bats at the water tray (see Analysis section below).

As the flight facility contained a limited number of flying invertebrate prey, we supplemented the bats' diets. First, we collected additional moths, flies, and beetles using a UV light trap placed outside the flight facility on a nightly basis. Second, following behavior trials, we hand-fed all bats mealworms (larval *Tenebrio molitor*) covered in a vitamin supplement (1/16 tsp. Bulk Supplements Pure Coenzyme Q10 (COQ10) to 2 tsp. Miracle Care Vionate Vitamin Mineral Powder; Lollar 2010). Evening bats were given approximately 5-8 small to medium-sized mealworms. Eastern red and Mexican free-tailed bats were fed 10-12 medium-sized mealworms, and hoary bats were fed 15-20 medium-sized mealworms (Lollar 2010).

Note that the Institutional Animal Care and Use Protocol (IACUC permit #14-01) included the necessary protocol for the housing and care of bats.

Drinking behavior trials

In 2014, we conducted drinking behavior trials to confirm the following: 1) that local bat species would attempt to drink from smooth metal surfaces (i.e., the surface most similar to water), as shown by Greif and Siemers (2010) with European bat species; and 2) that bats would attempt to drink at surfaces similar to those of wind turbine towers (i.e., a smooth painted metal surface). Thus, we created 2 treatment surfaces, a smooth metal and smooth painted surface. For the smooth metal surface, we used a 22 gauge aluminum plate (3.0 m x 1.2 m; Fig.8); and for the smooth painted treatment surface, we used paint-ready, 26 gauge galvanized steel plates (2.5 m x 1 m) and the same paint used on General Electric (GE) wind turbine towers deployed at operational wind facilities (Intergard 345 primer and Interthane 990 topcoat). We used rollers to apply two coats of primer followed by a topcoat (Fig. 8).

Smooth metal

Smooth painted

Figure 8. Images of 2 treatment surfaces used in drinking behavior trials in the bat flight facility during 2014.

After bats had acclimated to the flight facility, we first presented them with the smooth metal treatment surface. For this, we covered the water tray in the center of the room with the treatment surface. The next night, we kept the water tray uncovered to allow the bats full access to the water. If we did not observe the bats drinking from the water tray that night, we kept the water tray uncovered on subsequent nights until the bats drank again. Once we had observed bats drinking from the water tray again, we covered the water tray with the smooth painted treatment surface the following night. Note that individual bats were only presented with each treatment surface once, and in these trials only one bat was present in the flight facility at a time.

Before the bats emerged each night, we set up all equipment and covered the water tray with a treatment surface, when required (Fig. 9). To record all behavior and activities at the treatment surfaces, we used two Sony Handycam DCR-SX45 camcorders (Sony Corporation, New York, NY), one with an ATN NVM14-3 generation three night vision monocular (ATN Corporation, San Francisco, CA) attached (Fig. 10). We positioned both cameras side by side on a small platform that was elevated 0.25 m above the ground; the platform was placed 3.15 m away from the treatment surface (Fig. 11). We kept both cameras in the same location for the entirety of the survey period. Additionally, the cameras were set up to record all data onto 32 GB SD cards in MPG format. We also used two 450 nm infrared illuminators (ATN Corporation, San Francisco, CA) to allow us to continue to record bat activity in low light conditions (Fig. 11). The infrared lights were attached to the frame of the flight facility directly above the cameras with Jolby gorillapod tripods and were angled across the treatment surface to ensure that it was effectively illuminated.

Figure 9. The Sony camcorder view of the flight facility with a treatment surface placed over the water tray.

Figure 10. View of flight facility from the Sony camcorder with the night vision attachment.

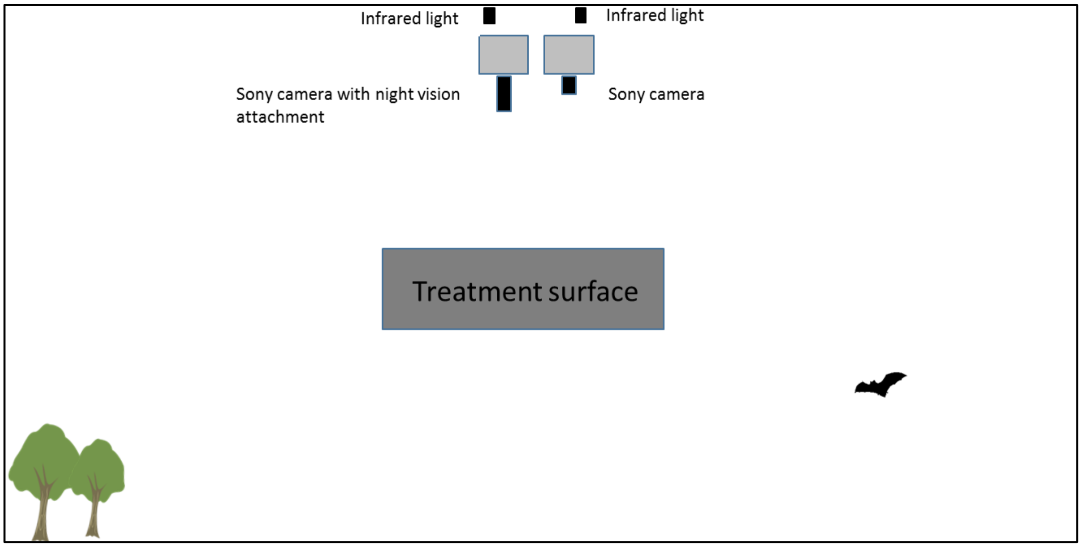


Figure 11. Diagram of bat flight facility set-up with 2 Sony camcorders and 2 infrared lights to record bat behavior at the treatment surface.

Once all the equipment was set-up, we waited for the first bat to emerge. If the bat emerged while there was still natural light, we initiated a drinking behavior trial by turning on the camcorder without the night vision attachment. If bats emerged in low light levels or when light levels diminished, we turned on the camcorder with the night vision attachment. As each camcorder was started, we verbally stated the date, time, and treatment surface. Throughout each trial, we also stated when the bat was active and its associated behavior in the flight facility.

A trial typically lasted 20 minutes, although there were instances in which we ended the trial early. In the preliminary behavioral surveys, we found that bats drank within 10-20 minutes of emerging from their day roosts. Thus, we conducted each drinking behavior trial for approximately 20 minutes post-emergence. Furthermore, preliminary surveys revealed that bats first make multiple straight-line flight paths across the longest extent of the tray prior to drinking water (Fig. 12). We defined this behavior as passing and a single path across the water tray was recorded as a pass. We noted that after a number of passes the bats would come close enough to the water tray to drink. Thus, during trials, once an initial pass had been made by the bat in the flight facility, we ended the experimental trial by removing the treatment surface when 1) 10 minutes had elapsed, 2) the bat did not make passes over the treatment surface for >2 minutes, or 3) the bat had stopped flying (i.e., became inactive) for >1 minute.

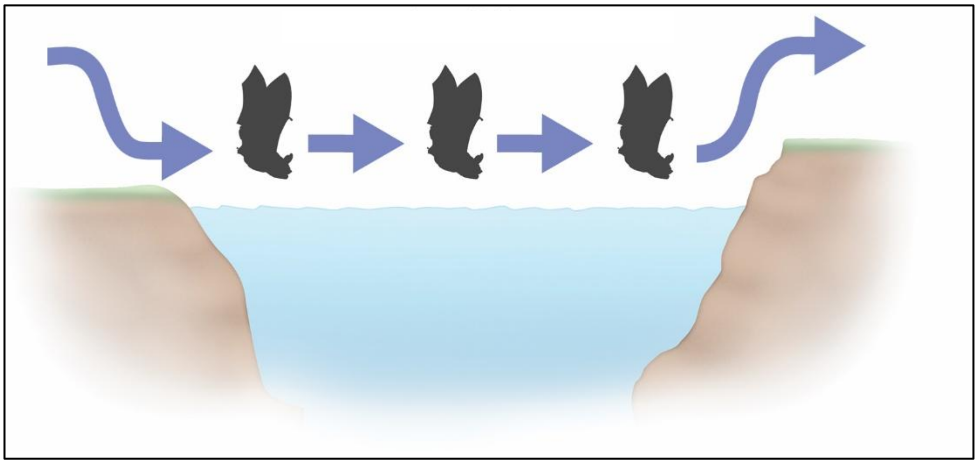
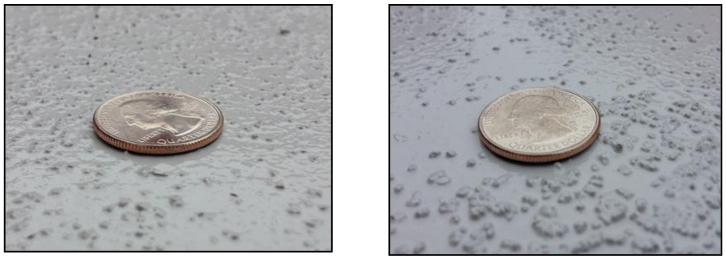


Figure 12. Illustration of straight-line flight path across a water source.

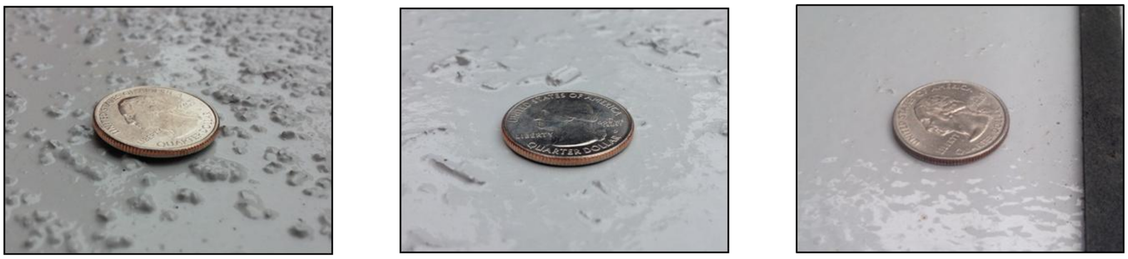
Texture trials

In 2015, we created an additional 6 new treatment surfaces for our behavior experiments: a smooth painted surface with the curvature of a wind turbine tower, 3 surfaces that varied in texture grade, a woodchip surface, and an appliqué (Fig. 13). To create these treatment surfaces, we again used paint-ready, 26 gauge galvanized steel plates (2.5 m x 1 m), Intergard 345 primer, and Interthane 990 topcoat.



Fine texture

Intermediate texture



Coarse texture

Woodchip

Appliqué

Figure 13. Images of 5 treatment surfaces created for texture trials in the bat flight facility during 2015. Note that the curved treatment surface is not shown here.

For the curved treatment surface, we used a custom-made “to scale” fiberglass section of a wind turbine tower (see Fig. 14 for specifications). The curvature of this section was equivalent to mid-tower height (~40 m above ground, which falls within the rotor swept zone) of a GE 1.5-megawatt wind turbine tower. We then placed the smooth painted plate over this fiberglass section to determine if bats would attempt to drink from a treatment surface that was similar to an operational wind turbine tower.

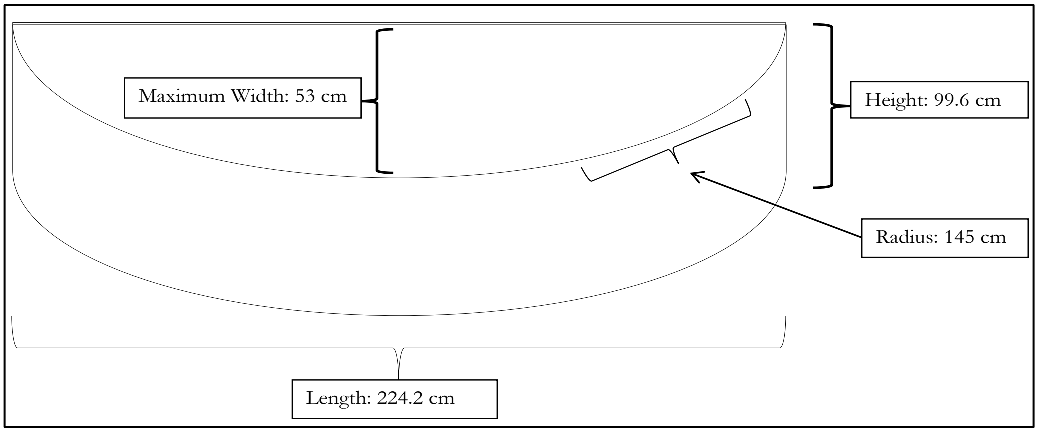


Figure 14. Specifications of the custom-made fiberglass wind turbine tower section that was placed in the bat flight facility.

For the textured treatment surfaces, we selected 3 different sand particle sizes that were visually distinct and would not compromise the integrity of the paint: U.S. Mesh 20/30 (595-841 microns, hereafter referred to as fine texture), U.S. Mesh 16/20 (841-1190 microns, intermediate texture), and U.S. Mesh 10/14 (1410-2000 microns, coarse texture; Fig. 13). For each of these texture treatments, we incorporated 2 cups of sand per 0.5 gallon paint into the second coat of primer before applying the topcoat. Similarly, for the woodchip treatment surface, we mixed 2 cups of woodchip (Alphapet: aspen 1500 in^3 bedding) per 0.5 gallon paint into the second coat of primer before applying the topcoat (Fig. 13). We considered this treatment surface to be representative of a texture the bats would encounter naturally and wanted to determine if bats would be attracted to or show more interest in such a texture. For example, a recent study by Cryan et al. (2014) suggested that the size and shape of wind turbines may cause bats to mistake turbines to be trees. Thus, we wanted to explore whether coating a turbine tower with a texture similar to tree bark would further encourage bats to come into contact with the wind turbines. Finally, we created an appliqué treatment surface by adhering 12.7 mm tall x 19 mm wide x 1 m long strips of ACE Tight Fit Foam Tape perpendicular to the long-axis of a smooth painted plate at 0.5 m intervals (Fig. 13). The selection of this surface was based on a study conducted by Yuen (2015) in which synthetic bat calls were played at treatment surfaces in a sound-dampened room. Yuen (2015) showed that the edges of the plates reflected echoes back toward the sound source, suggesting that artificial "edges" on top of a smooth surface could potentially dissuade bats from coming in to drink (see also Greif and Siemers 2011).

Once approximately 6 bats had acclimated to the flight facility, we presented the bats with 1 of the 7 treatment surfaces (i.e., the smooth painted surface used in 2014 and 6 treatment surfaces created in 2015). Note that 1) the order these treatment surfaces were presented to the bats was random, 2) individual bats were only presented with each treatment surface once, and 3) drinking behavior trials were conducted every other night to allow bats full access to the water tray on alternating nights. If we did not observe the bats drinking from the water tray following a survey night, we supplemented bats with water from pipettes, and the water tray remained uncovered on subsequent nights until the bats once again drank on their own.

As in 2014, the 20 minute experimental trial was initiated when the focal bat emerged from its day roost. The trial ended when either 20 minutes had elapsed or if a bat (not necessarily the focal bat) had been active for 10 minutes immediately following the initial pass. We then removed the surface from the water tray to ensure that the bat attempting to drink had access to water for its well-being. We performed additional texture trials within the night on the occasions when some bats emerged after the first trials were completed. These additional trials were conducted when 1) individual bats emerged after the water tray had been available to bats included in the previous trials >20 minutes, 2) bats included in the previous trials successfully drank, 3) bats that emerged during the 20 minute period following previous trials had had access to the water tray for an additional 20 minutes, or 4) bats that emerged during the 20 minute period following previous trials had successfully drank.

Prior to an experimental trial survey night, we set up all equipment and covered the water tray with a treatment surface (Fig. 15). To effectively record all behavior and activities near the treatment surfaces, we placed 2 Canon XA20 camcorders (Canon Inc., Melville, NY) at 90° from one another with their fields of view centered on the treatment surface (Fig. 16). The side-view camera (Fig. 17) was positioned 3 m from the treatment surface, and the front-view camera (Fig. 18) was 3.15 m from the surface. For the entirety of the survey period, we placed both cameras in the same location with the same tripod height (side-view: 1.25 m from the ground; front-view: 0.5 m from the ground). The cameras were set up to record all data onto 64 GB SD cards in MP4 format. We also used an 850 nm infrared LED light bar (Larson Electronics LLC, Kemp, TX) to allow us to record bat activity in low light conditions (Fig. 16). Note that the location of this infrared LED light was kept in the same location each survey night; it was placed on the ground by the side-view camera and was angled towards the ceiling of the flight facility to ensure the flight facility was effectively illuminated (Fig. 16).

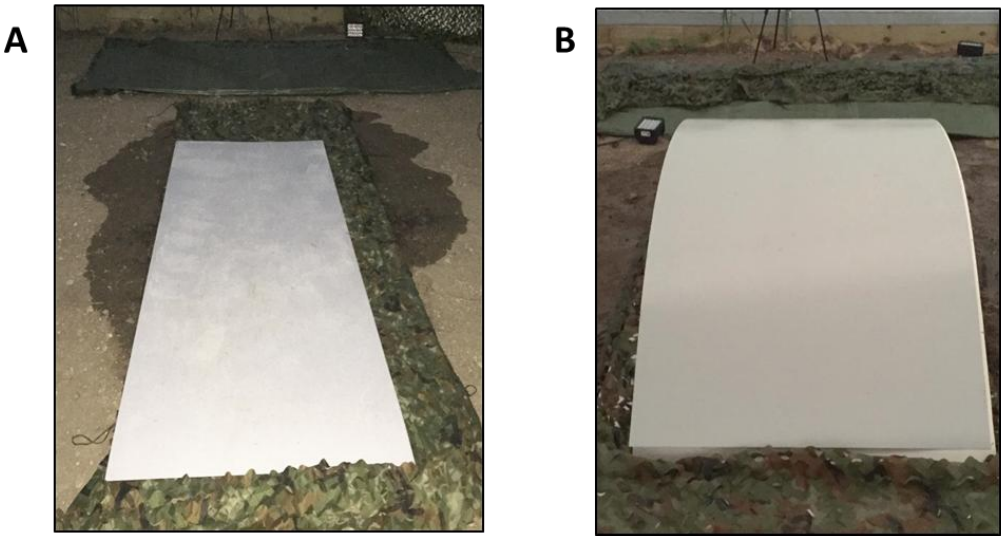


Figure 15. Placement of treatment surfaces over the water tray. Image A shows a flat treatment surface, and B shows the smooth painted plate covering the curved fiberglass wind turbine tower section.

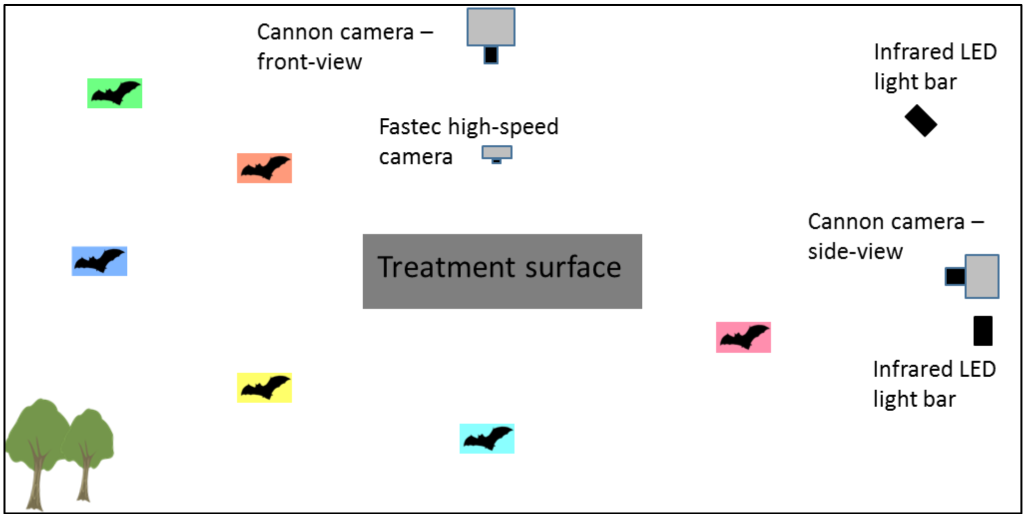


Figure 16. Diagram of bat flight facility set-up with 2 Canon XA 20 camcorders placed at right angles from each other on tripods and a Fastec IL4 high-speed mono imaging camera placed at ground level to record bat behavior at the treatment surface.

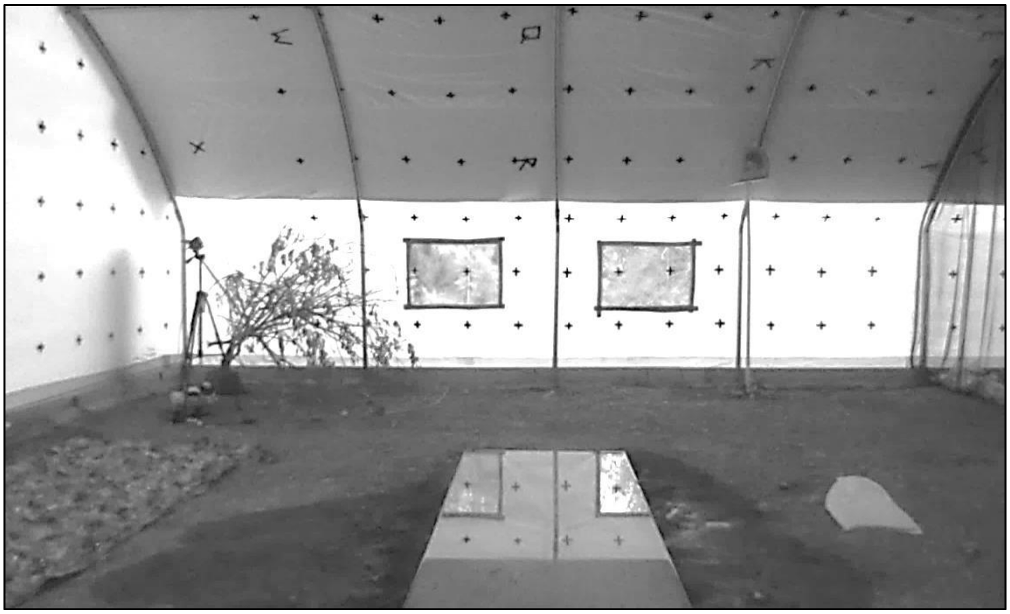


Figure 17. Canon XA20 camcorder side-view of flight facility.

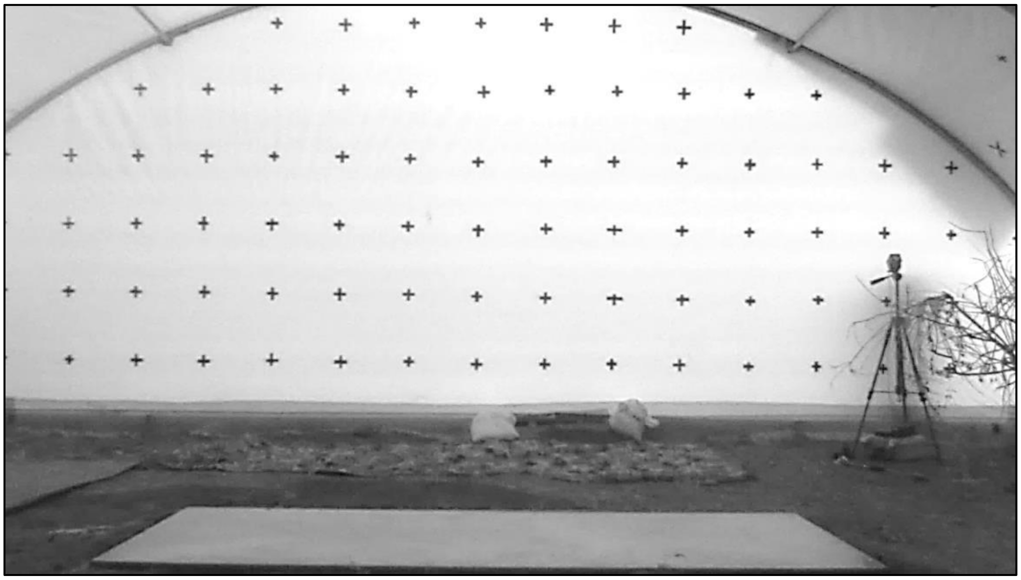


Figure 18. Canon XA20 camcorder front-view of flight facility.

In addition, we used a Fastec IL4 100 high-speed mono imaging camera (South Central Imaging, Ltd., Westfield, IN) with a 17 mm lens (f 0.95) to record multiple high-resolution, close-up images that were used to more accurately identify interactions with treatment surfaces (Fig. 16). For the 6 flat treatment surfaces, we placed the high-speed camera ~1 m from and perpendicular to the treatment surface using a sandbag and section of foam to make a level surface for camera placement (Fig 19 A). For the curved treatment surface, we placed the camera and sandbag on top of a small platform (0.5 m from the ground) and positioned the platform at 45° from the corner of the treatment surface (Fig. 19 B). The high-speed camera was connected to a laptop with an ethernet cable and operated through Fastec FasMotion Controller (Larson Electonics LLC, Kemp, TX). Using live-feed images, we then focused the high-speed camera by placing a rubber duck in the center of each treatment surface (Fig. 20). We also set the camera to take images at 290 fps using a shutter speed of 3630 µsec and saved these images onto the 256 GB internal SSD. Finally, we used a second 850 nm infrared LED light bar to provide additional illumination at each treatment surface when using the high-speed camera. This second light was placed near the first LED light, but was angled towards the back corner of the flight facility across the treatment surface (Fig. 16). We also had to adjust the height of this light between flat and curved treatment surfaces (0.25 m and 0.5 m above ground, respectively).

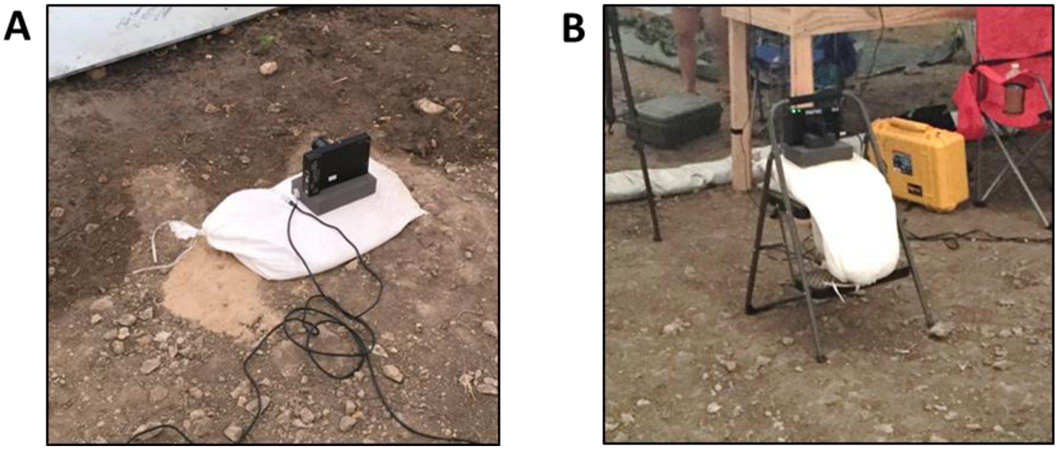


Figure 19. Images demonstrating the placement of the high-speed camera. Image A shows the camera set-up for flat treatment surfaces and B shows the camera set-up at the curved treatment surfaces.

Figure 20. Image showing rubber duck used to focus the high-speed IL4 camera on the center of a treatment surface.

Once all the equipment was in place, we waited for the first bat to emerge and initiated a drinking behavior trial by turning on the Canon cameras and infrared LED lights. We then verbally stated the date, time, and treatment surface used in the trial. For our analysis (see below) we needed to be able identify individual bats (such as the focal bat); however, the cameras used did not have color capability. Thus, throughout the trials, we verbally identified the UV pigment color and associated behavior of each bat that was active in the flight facility. At the end of each trial we turned off each camera. Note that due to limited space on the internal SSD of the high-speed camera, we only recorded bat activity on this camera when bats began flying within close proximity to the treatment surface.

Analysis

Drinking behavior trials

We processed all video files from the Sony camcorders with Studiocode (version 5, Studiocode Business Group, Sydney, AU). In order to open the video files within the program, we first converted each MPG file to an MP4 file with Windows Movie Maker (version 2012, Microsoft Corporation, Redmond, WA). We then opened each MP4 video within Studiocode. To aid in the analysis of the videos, we created a code window in Studiocode (Fig. 21). This code window contained 2 code buttons and 4 label buttons. The first code button was created to identify when a bat was active. To isolate specific bat behavior, a second code button was created to identify contact with the treatment surface (i.e., when a bat touched the treatment surface with any body part) or identify a drinking event at the water tray (i.e., when a bat made contact with the water to drink). We then created 3 buttons to identify each treatment surface specifically associated with contact (Fig. 21).

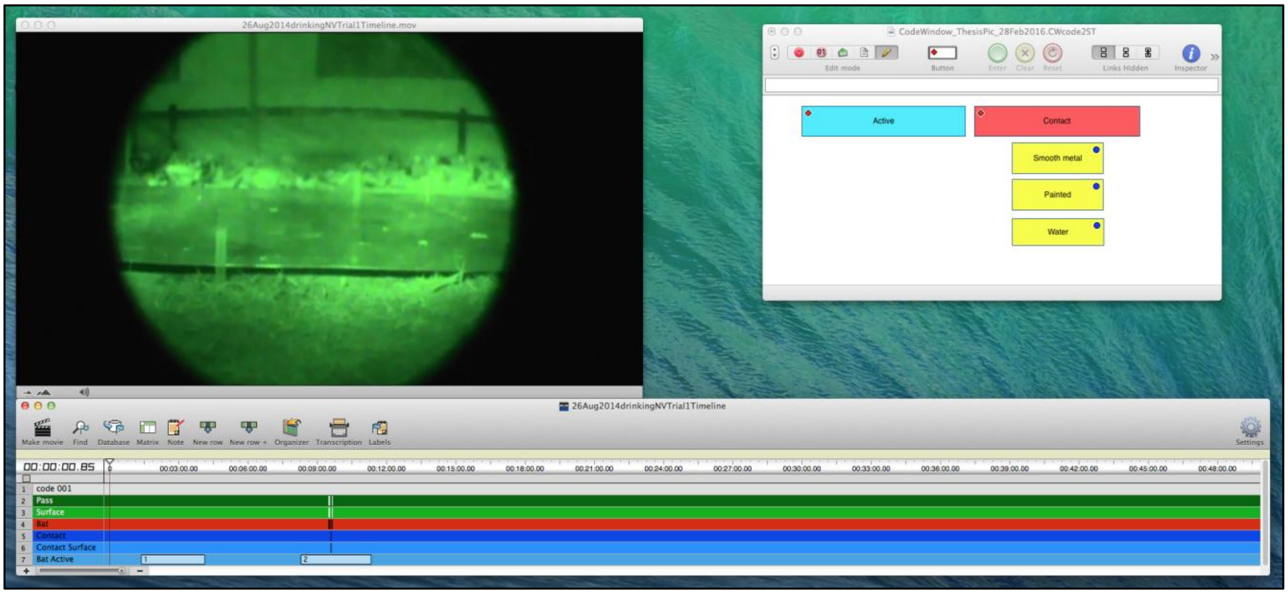


Figure 21. Night vision video of smooth metal treatment surface opened within Studiocode. Image included the code window used to analyze videos in Studiocode. Code buttons include activity (blue) and behavior (red). Label buttons include the treatment surfaces (yellow).

For the analysis, we watched each video (i.e., we did not use automated software to analyze videos). We used the code window to select the appropriate individual from the list provided in the code window, identify when the bat was actively flying throughout the trial, and indicate when the bat made contact with the treatment surface. After coding a video, we exported the data to an Excel file and merged it into a single master Excel spreadsheet for analysis. Once all the videos had been coded and the data exported and merged, we used the data to compare the number and rate of contacts made by bats with each treatment surface to the number of drinking events at the water tray.

We treated each individual bat successfully tested in the flight facility as an independent sampling unit. Multiple individuals from both solitary and colonial species were present in the flight facility at once. We speculate that colonial individuals may have influenced other individuals in the flight facility. For example, evening bats were observed to emerge from their day roost shortly after one another, and in preliminary surveys we also observed multiple individuals from different species making passes over the treatment surface and drinking from the water tray simultaneously. Field studies frequently observed multiple individuals of several bat species drinking at the same water source simultaneously (Adams and Thibault 2006, Lopéz-González et al. 2015); thus, we do not believe that inter-specific or inter-individual interactions influenced bat behavior at the experimental surfaces. We therefore analyzed the data with all individuals together and by species.

To compare the number of contacts with the treatment surface to the drinking events at the water tray, we totaled the number of contacts made by each individual bat at the smooth metal treatment surface, smooth painted treatment surface, and water tray during each trial. We used these data to first confirm that local bat species attempted to drink from our 2 treatment surfaces. We then determined the rate of contact for each bat by dividing the number of contacts by the duration of each trial and then multiplied these values by 5 to get the number of contacts made on a per 5 minutes basis. Finally, we compared these rates to ascertain whether bat behavior at the 2 smooth treatment surfaces differed from bat behavior at water.

Texture trials

In Studiocode, we first synchronized the side-view and front-view videos by using the date stated at the beginning of each trial. Alternatively, if a bat was in both camera views at the start of the trial, we used that individual to visually synchronize the videos. We then used the stacking tool in Studiocode to merge the videos onto one timeline (hereafter referred to as a paired video), allowing us to view both camera angles simultaneously (Fig. 22).

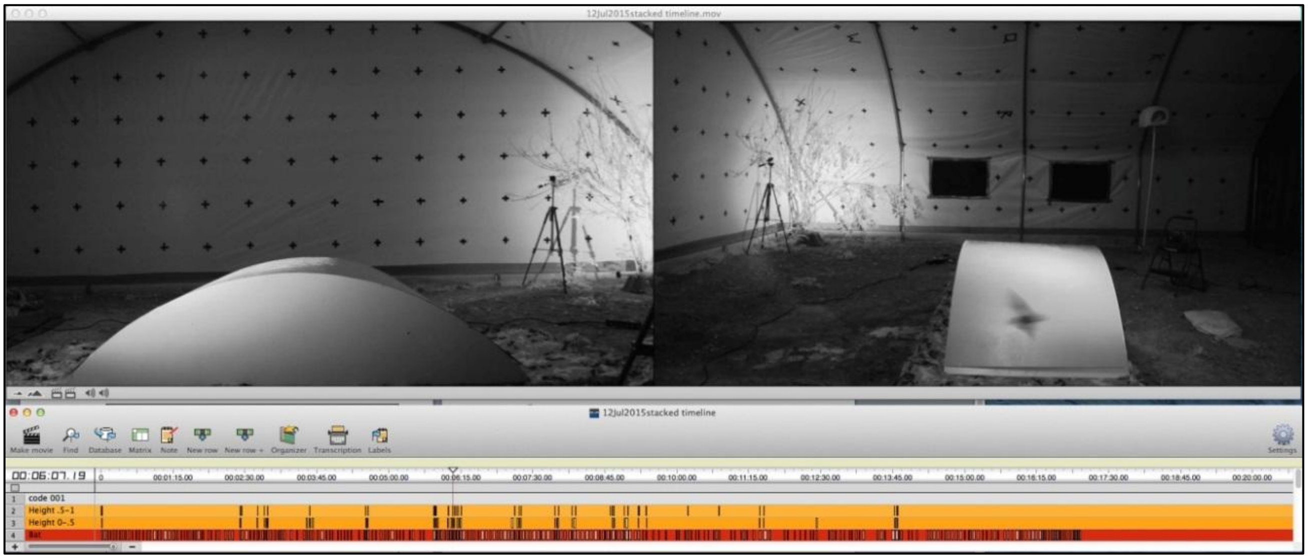


Figure 22. Front-view and side-view of Canon XA20 videos paired together on one timeline within Studiocode.

To aid in the analysis of the paired videos, we created a code window in Studiocode (Fig. 23). This code window contained both code buttons and label buttons. A set of code buttons was created to identify the position of bats relative to the treatment surface. Using distance markers on the walls of the facility, we divided the front camera view into seven 0.5 m high horizontal zones (i.e., 7 code buttons). A single code button was used to depict the vertical space above the treatment surface in the side-view (Fig. 23). In addition, 2 code buttons were created to identify specific bat behavior: 1) passing and 2) contact with the treatment surface (defined below).

We then created 2 sets of label buttons: 1 set of 8 label buttons was created to identify each treatment surface specifically associated with either passing or contact (defined below). Furthermore, we created a single label button that contained a selectable list of uniquely marked individual bats (i.e., UV color combinations). Finally, we included a single action button which could control all code buttons simultaneously which made video analysis more efficient. We then increased the transparency of the code window and overlaid it onto the paired videos for analysis (Fig. 24).

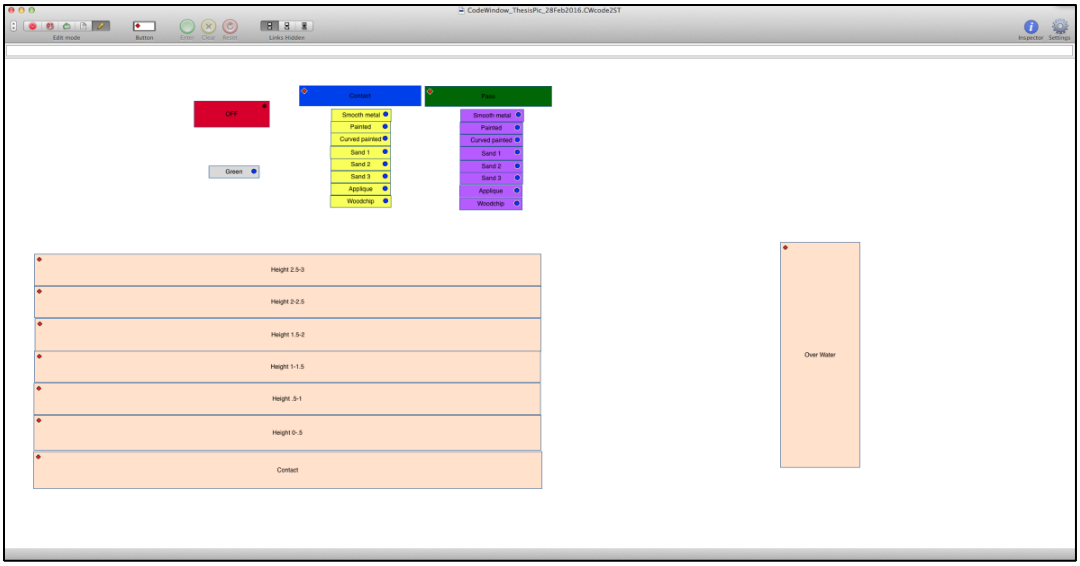


Figure 23. Screenshot of the code window used to analyze paired videos in Studiocode. Code buttons include horizontal and vertical zones (orange) and behaviors (blue and green). Label buttons include the treatment surfaces (yellow and purple) and the list of marked individuals (grey). The action button is shown in red.

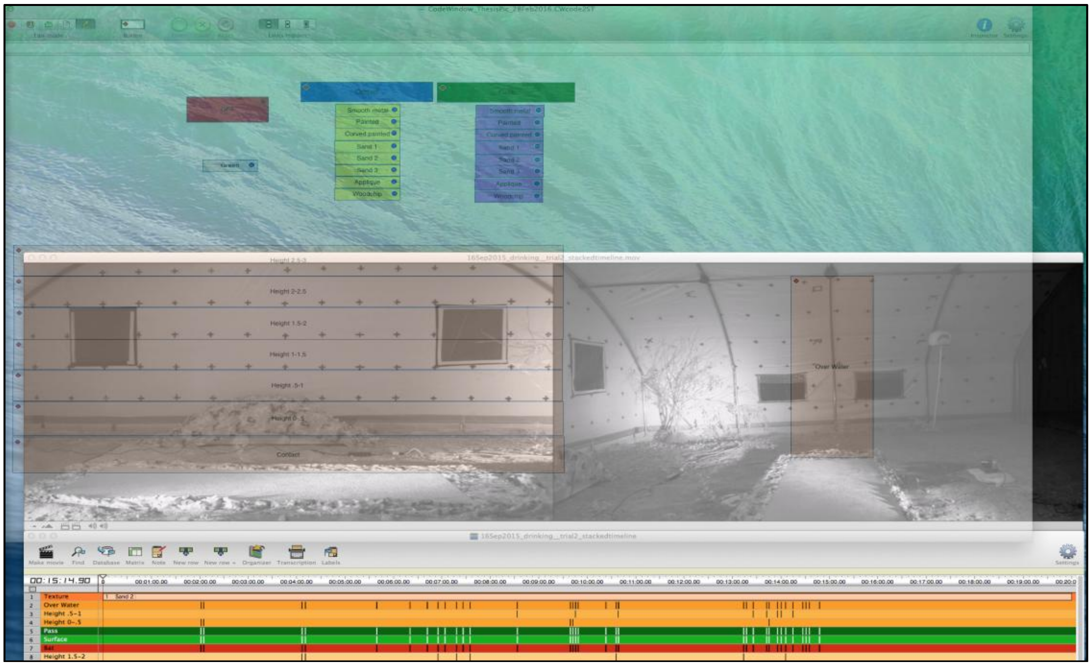


Figure 24. Image of the transparent code window overlaid on each paired video.

For the analysis, we manually watched each paired video; and when a bat flew through the vertical air space across the length of the treatment surface, we first used the audio file to determine the identity of the bat. Based on this identity, we selected the appropriate marked individual from the list provided in the code window. Using the code window, we then identified when the bat entered the vertical space above the treatment surface, the behavior the bat exhibited in the vertical space, and the horizontal zone in which the bat came closest to the treatment surface.

If a bat appeared to come within 0.25 m of the surface, we then used Fastec images to confirm contact. Contact with a treatment surface was confirmed when a bat touched the treatment surface with any body part (e.g., tongue, wings, feet, uropatagium, etc.). The images showing the bats approaching and making contact with a treatment surface were saved to an external hard drive as AVI files at 20 fps. Once contact had been confirmed, we used the code window to identify the corresponding behavior in the paired video (Fig. 25).

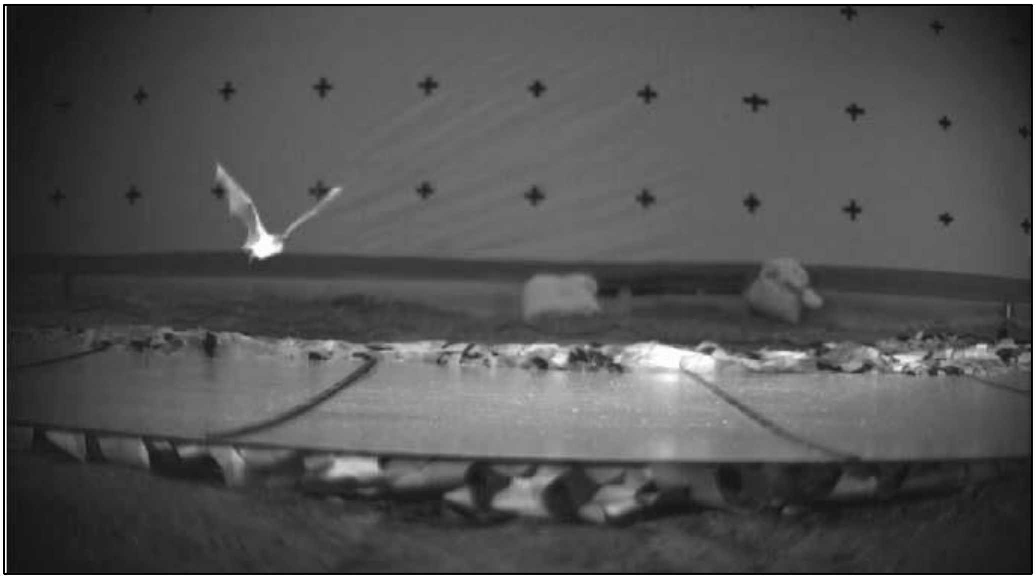


Figure 25. Image from the Fastec IL4 high-speed mono camera view of the appliqué treatment surface on camouflage netting over the water tray.

After coding a paired video, we exported the data to an Excel file and merged it into a single master Excel spreadsheet for analysis. Once all the paired videos had been coded, and the data exported and merged, we used the data to determine 4 response variables: 1) number of contacts with the treatment surface or number of drinking events at the water tray; 2) number of passes across the treatment surface or water tray (this value includes the number of contacts with each treatment surface and drinking events at the water tray); 3) closest approach to a treatment surface by each bat during a pass; and 4) time until a bat first approached each treatment surface or the water tray. With these variables, we conducted the following analysis and where possible used statistical tests to compare the results.

To determine the number of contacts with the treatment surface, we totaled the number of contacts made by each individual bat during a 5 minute period after the first contact was made with the treatment surface. We then averaged the number of contacts per bat across each treatment surface. Finally, to determine if treatment surface influenced whether bats made contact with a surface, we compared these mean values with the mean number of drinking events made at the water tray (see below) to determine whether the contact rate varied between water and the different treatment surfaces.

To determine the number of drinking events at the water tray, we counted the number of drinking events within a 5 minute period following the initial pass made over the water by an individual bat. For this, we used voice recordings from each acclimation night. We averaged the number of drinking events per bat and then used this mean in the analysis described above.

To determine the number of passes in each paired video, we counted the total number of passes made by an individual bat within a 5 minute period following its first pass over a treatment surface or the water tray. We excluded passes by bats whose identities were not known and bats that were not exposed to the treatment surface for a full 5 minutes from the analysis. To determine if the treatment surface influenced the number of passes made by bats across a surface, we compared the mean number of passes per bat between treatment surfaces and water.

For closest approach to treatment surface, we used the horizontal zones in the code window to determine the distance at which the bats came closest to each treatment surface during a trial. We totaled the number of passes made by an individual bat in each horizontal zone for each treatment surface. We then averaged the total number of passes and compared these means between zones and treatment surfaces.

Lastly, for time until first pass, we used video timestamps to calculate the time it took for a bat to make its first pass over a treatment surface or the water tray from the time that bat emerged. To determine if treatment surface influenced the time when bats first approached a surface, we compared the average approach time between the treatment surfaces. We used a Kruskal-Wallis test to determine if these results were statistically significant. Note that $\alpha = 0.05$.

RESULTS

Drinking behavior trials

In 2014, 4 bat species were captured in our mist nets: 2 (2 female) eastern red bats, 2 (2 male) evening bats, 1 (1 female) Mexican free-tailed bat, and 2 (2 male) hoary bats. The latter 2 species as well as 1 eastern red bat were not included in our trials or analysis as they did not successfully acclimate to the flight facility. Thus, a total of 6 behavioral trials were conducted from July 16 to September 13, 2014 with a total of 3 individual bats (2 evening and 1 eastern red). All trials were successfully processed and analyzed in Studiocode to determine the number and rate of contact at each surface.

In the trials, we recorded bats making contact at both smooth metal and smooth painted treatment surfaces. Each individual bat (n = 3) made multiple contacts with the smooth metal treatment surface. Although the video quality was not good enough to confirm that the eastern red bat contacted the smooth painted treatment surface, we recorded evening bats (n = 2) making multiple contacts with this treatment surface.

When comparing the rate of contact per 5 minutes with the water tray and two treatment surfaces, we observed fewer contacts at the water tray (mean ± SE = 1.8 ± 0.7, Fig. 26). The mean rate of contacts for the smooth metal and smooth painted treatment surfaces were more similar to each other than to water; however, we observed a higher rate of contact with the smooth metal treatment surface (mean ± SE = 18.3 ± 3.9) than the smooth painted treatment surface (mean ± SE = 12.4 ± 4.0).

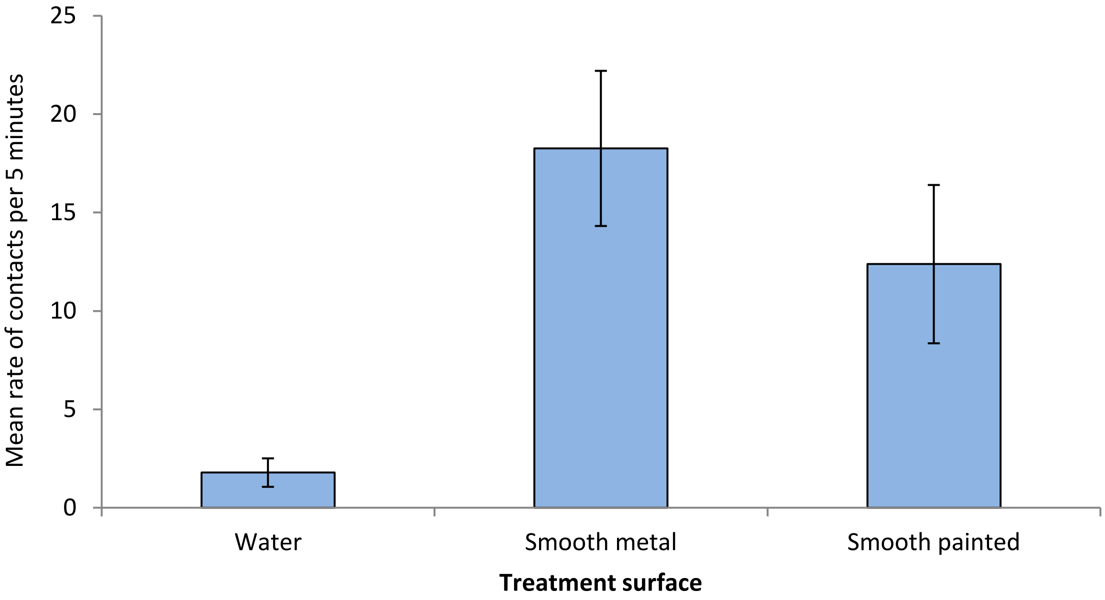


Figure 26. Mean rate of contact per 5 minutes at each treatment surface and the number of drinking events at the water tray. Bars represent ± SE.

Texture trials

In 2015, we captured 3 species of bats in mist nets: 5 (1 female; 4 male) eastern red bats, 36 (19 female; 17 male) evening bats, and 12 (11 female; 1 male) Mexican free-tailed bats. The latter species was not included in our trials as they did not successfully acclimate to the flight facility. A total of 64 behavioral trials were conducted from June 10 to September 25, 2015 with 41 individual bats. Sixty-one trials were successfully processed and analyzed in Studiocode. The 3 excluded trials included 1 smooth painted, 1 fine texture, and 1 appliqué treatment surface, as standing water was present on the surfaces during those trials and, therefore, compromised these trials.

Number of contacts with treatment surfaces and water tray

We recorded eastern red and evening bats making contact (drinking attempts as well as wing and uropatagium contacts) with 3 of the 7 surfaces: smooth painted, curved, and appliqué treatment surfaces (i.e., all of the non-textured treatment surfaces, Fig. 27). Note that although the appliqué treatment surface had strips of foam tape adhered to its surface, the majority of this treatment surface was smooth painted metal. When comparing the mean number of contacts made by bats at textured treatment surfaces (i.e., the fine texture, intermediate texture, coarse texture, and woodchip), we did not observe bats coming into contact with any of the textured treatment surfaces. Note that we observed the highest mean number of contacts at the water tray.

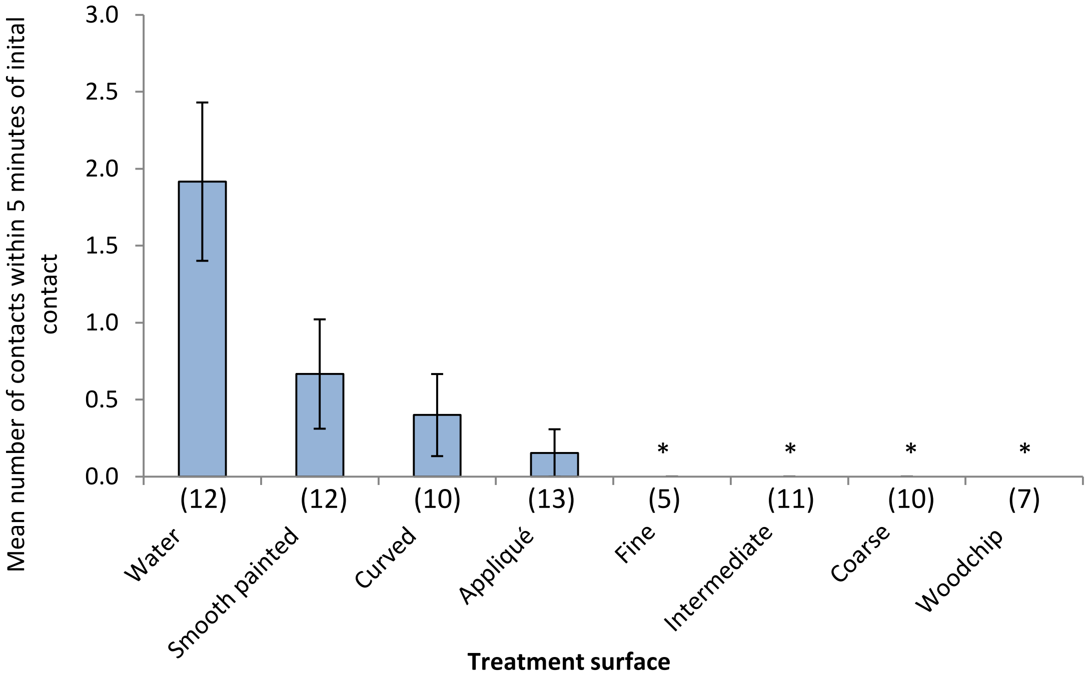


Figure 27. Mean number of contacts made at each treatment surface and number of drinking events at the water tray within 5 minutes of the bats' initial contact. An * indicates treatment surfaces that bats did not contact. Bars represent ± SE. The number of bats included for each treatment surface is shown in parentheses.

To identify the relative influence of a single bat species on our results, we removed the eastern red bats from the dataset and again calculated the mean number of contacts at each surface (Fig. 28). We found that contact at the appliqué treatment surface was driven by eastern red bats as evening bats did not contact this treatment surface.

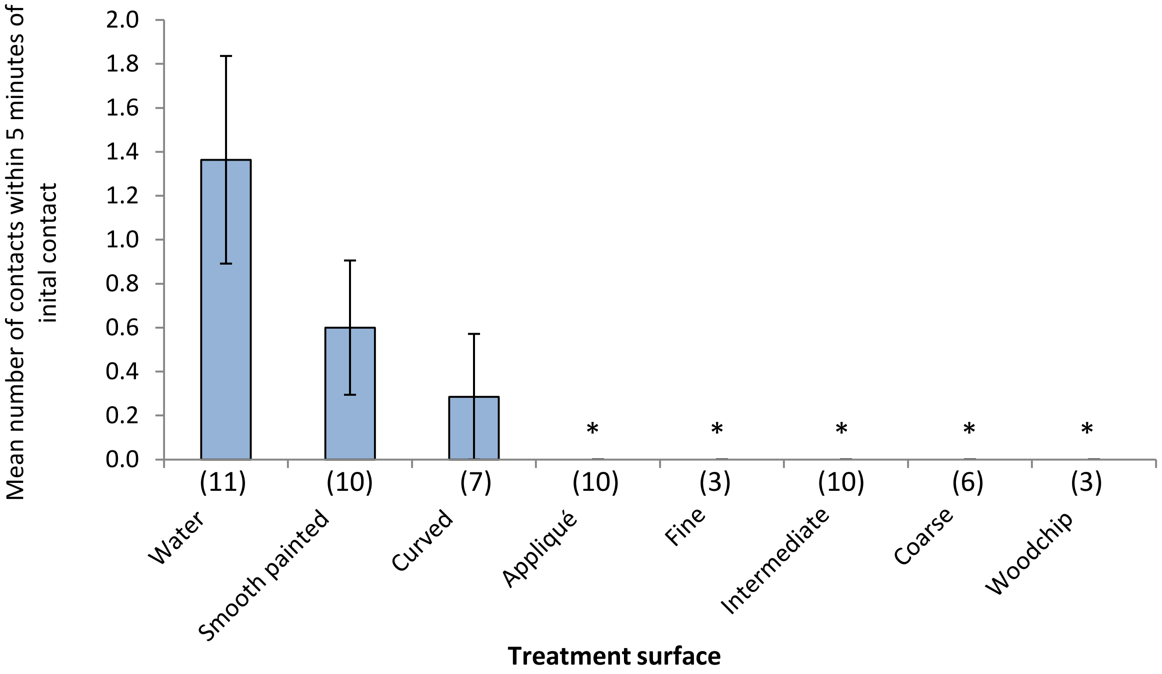


Figure 28. Mean number of contacts made at each treatment surface and number of drinking events at the water tray within 5 minutes by evening bats. An * indicates treatment surfaces that bats did not contact. Bars represent ± SE. The number of bats included for each treatment surface is shown in parentheses.

Number of passes across treatment surfaces and water tray

A total of 643 passes were made over the treatment surfaces by 28 individual bats. After the initial pass was made in each trial, a total of 351 passes occurred within 5 minutes. Using these data, we found that mean number of passes at the smooth painted and curved treatment surfaces were very similar to the mean number of passes at the water tray (Fig. 29). In contrast, the highest mean number of passes across all smooth and textured treatment surfaces occurred at appliqué. We found that the number of passes across the sand-based textured treatment surfaces increased with increasing texture gradient. Additionally, removing eastern red bats from the data set did not alter this pattern.

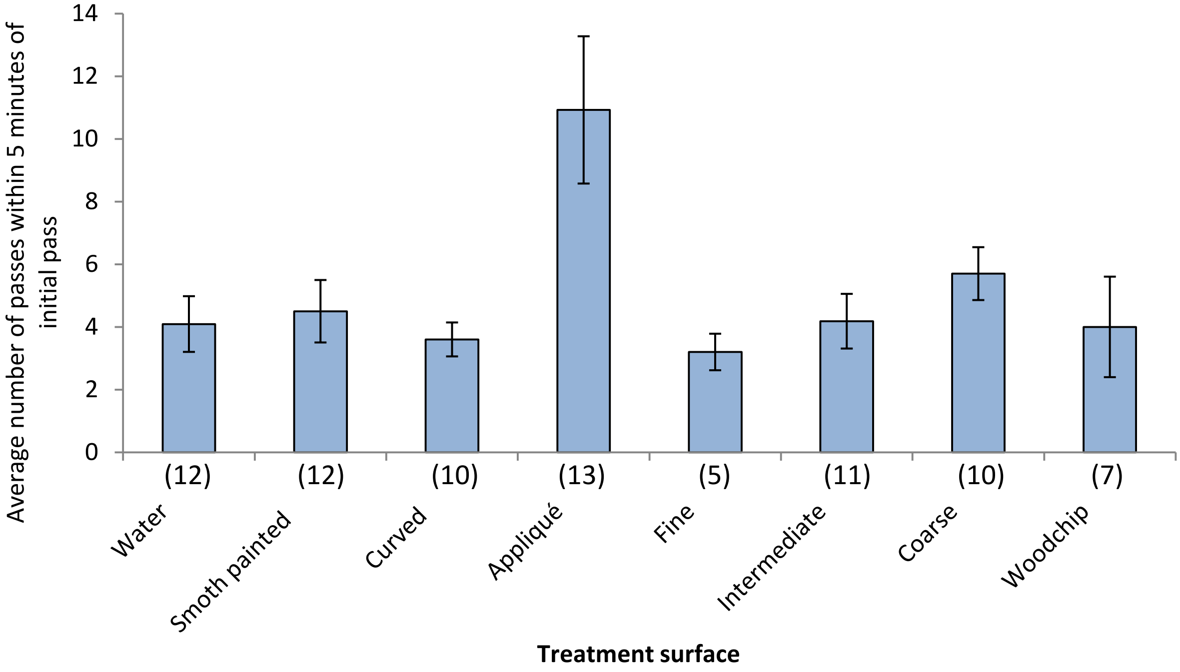


Figure 29. Mean number of passes made within 5 minutes of the bats' initial pass across the treatment surface. Bars represent ± SE. The number of bats included for each treatment surface is shown in parentheses.

Note that there are 2 differences between sand-based textured treatment surfaces: 1) particle size and 2) gap size between particles (i.e., density of particles). To determine if the size of gaps between particles on the treatment surfaces influenced the number of bat passes, we measured the distance between particles on the fine, intermediate, and, coarse textured treatment surfaces. To measure gap distance, we randomly selected and photographed five 0.1 x 0.1 m areas from the fine, intermediate, and coarse texture surfaces which were then uploaded into a photo analyzing software program, ScanSigma Pro (version 5.0, Systat Software Inc., Point Richmond, CA). Using ScanSigma Pro, we gridded each image with 0.01 x 0.01 m cells (100 cells total; Fig. 30 A) and randomly selected 30 cells. Within each cell, we measured the distance from a particle near the center of the cell to the closest particle above it (Fig. 30 B).We began and ended each measurement at the center of the particles. Note that we did not include the woodchip treatment surface in this analysis as the particles did not have the same structure and shape as the sand particles; therefore, the woodchip treatment surface could not be measured using the same method as sand treatment surfaces. The distance measurement for each pair of particles was exported to Excel. To determine if the size of gaps between particles on each treatment surface was significantly different, we compared mean gap distances with ANOVA and Tukey Kramer tests ($\alpha = 0.05$). Finally, to determine if there was a relationship between gap size in each treatment surface and the average number of passes made by individual bats, we performed a linear regression analysis on the number of passes per bat (natural log transformed) and the mean gap size of the corresponding treatment surface (fine, intermediate, and coarse textures).

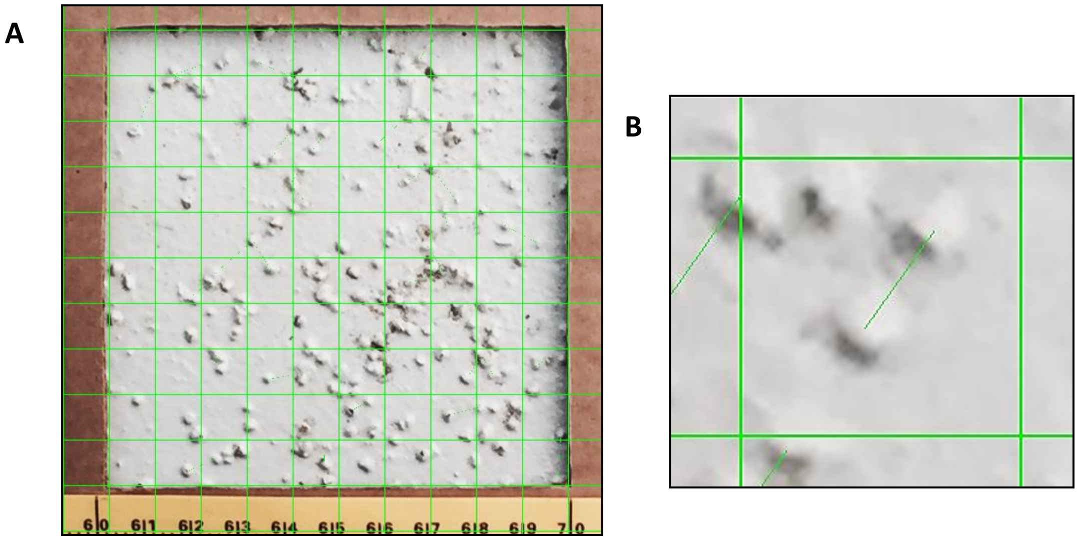


Figure 30. Images of course texture treatment in ScanSigma Pro. Image A shows a gridded 0.1 x 0.1 area, and image B shows a 0.01 x 0.01 m cell with a demonstration (green diagonal line) of the distance we measured between 2 particles on the treatment surface.

We found that mean gap size varied among our treatment surfaces, with greater distances for coarse texture than for the intermediate texture, and that both were greater than for the fine texture (ANOVA, $F_{2,447} = 144.11$, $P<0.001$). Pairwise post-hoc Tukey test revealed that gap distance differed significantly among all treatment surfaces ($P<0.001$ in all cases, Fig. 31). Furthermore, we found a strong positive linear relationship between mean number of passes per bat and mean gap size of each treatment surface (Fig. 32).

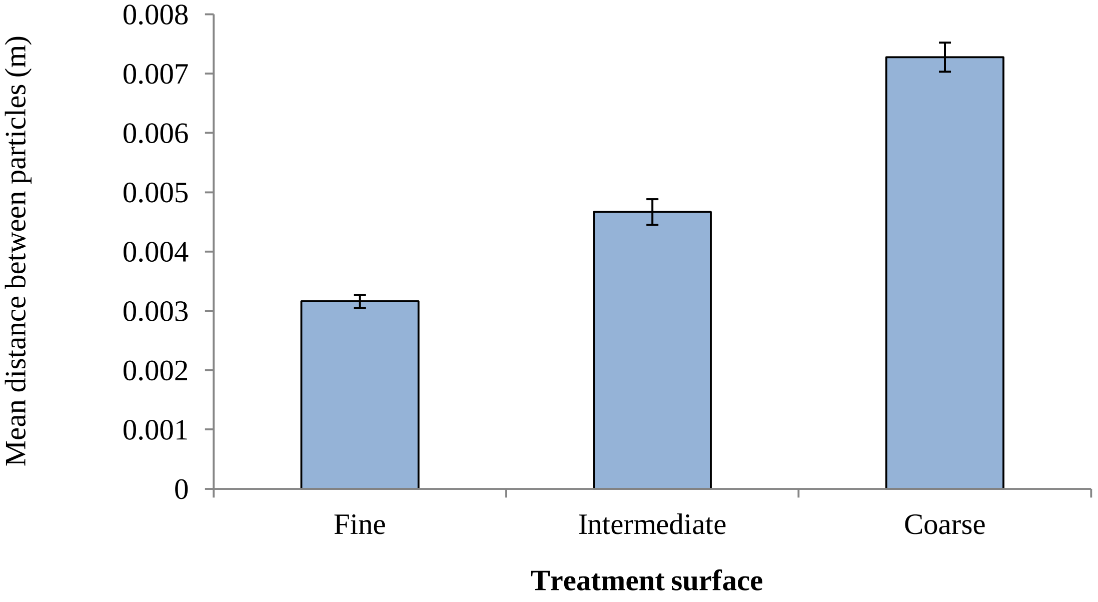


Figure 31. Mean distance between particles on treatment surfaces. Bars represent ± SE.

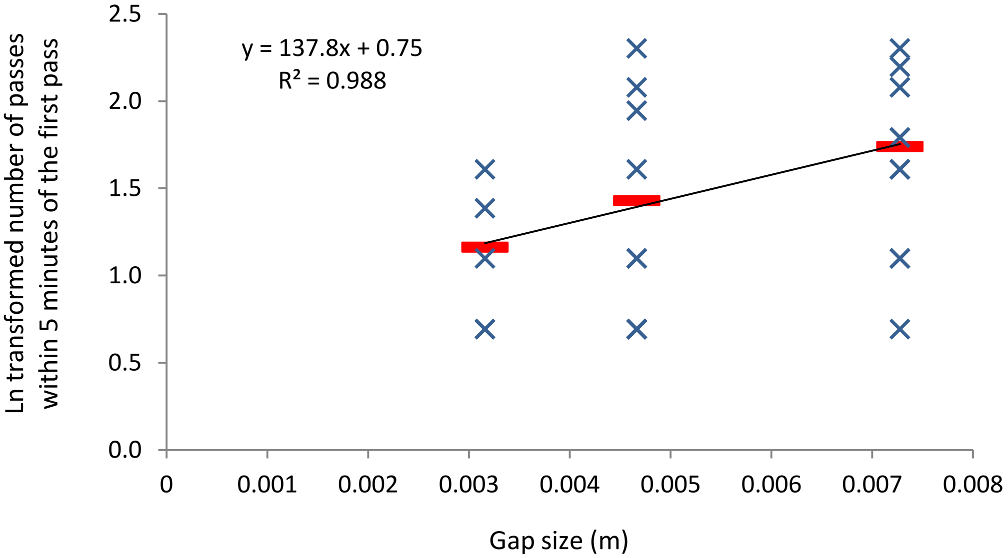


Figure 32. The number of passes within 5 minutes of the first pass made by individual bats increased with gap size across the three textured treatment surfaces (fine, intermediate, and coarse textured treatment surfaces). Horizontal red lines indicate the mean number of passes associated with each gap size, and the black line is the linear regression line.

Closest approach to treatment surfaces

From the 351 passes recorded, all of these bat passes occurred within 0 to 1 m from the treatment surfaces, and the majority of these passes occurred within 0.5 m of each treatment surface. The mean number of passes within 0.5 m varied between the surface treatments (Fig. 33); yet, the mean number of passes within 0.5 to 1 m did not vary among surface treatments (Table 1). Additionally, removing eastern red bats from the data set did not alter our results.

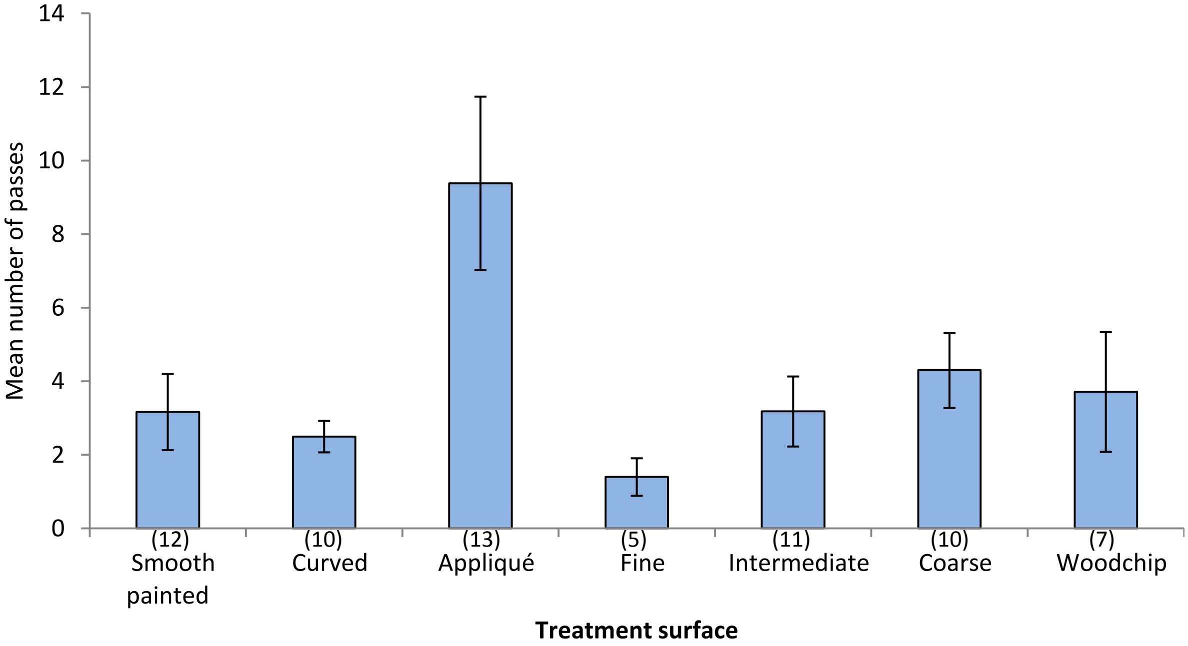


Figure 33. Mean number of passes occurring within 0.5 m from the treatment surfaces. Bars represent ± SE.

Table 1. Mean (± SE) number of passes within each distance zone away from the treatment surface.

	Distance (m)		
Treatment surface	0.5-1.0	1.0-1.5	1.5-2.0
Smooth painted	1.17 (0.37)	0 (0)	0 (0)
Curved	0.90 (0.31)	0 (0)	0 (0)
Fine texture	1.00 (0.32)	0 (0)	0 (0)
Intermediate texture	1.09 (0.62)	0 (0)	0 (0)
Coarse texture	1.40 (0.31)	0 (0)	0 (0)
Appliqué	1.46 (0.86)	0 (0)	0 (0)
Woodchip	0.43 (0.30)	0 (0)	0 (0)

Time until first pass at treatment surfaces and water tray

Comparing the time until the bats made their first pass over each treatment surface and the water tray, we did not observe any noticeable trends (Fig. 34) and removing eastern red bats from the data did not result in a noticeable trend. A Kruskal-Wallis test of the combined data for eastern red and evening bats confirmed that there was no significant difference for the time until first pass among all treatment surfaces and the water tray (H = 9.51; df = 6; P = 0.15). Additionally, removing eastern red bats from the data set did not alter this pattern.

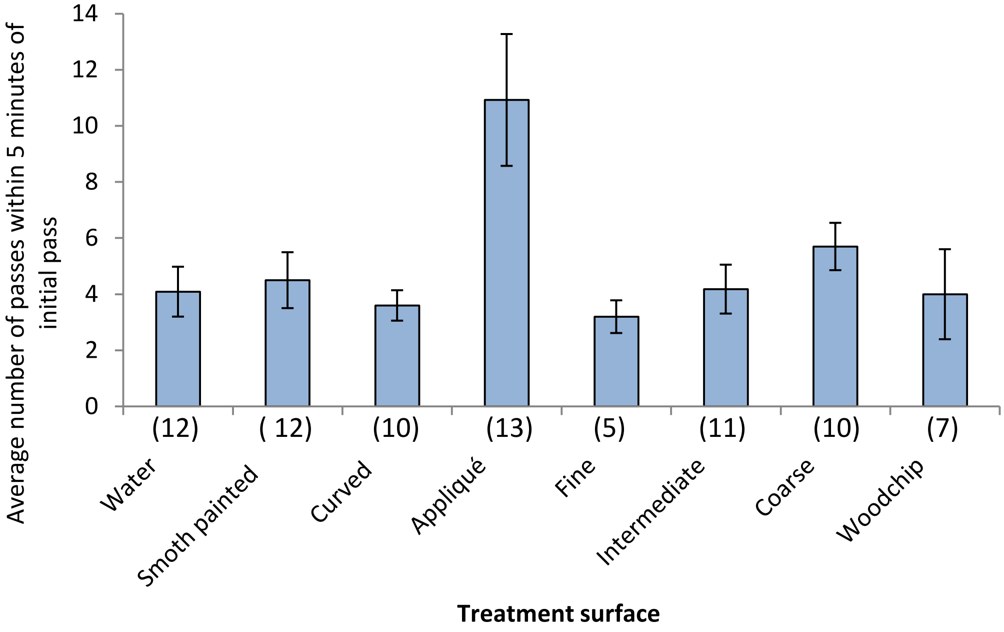


Figure 34. Mean time (minutes) for bats to make their first pass over each treatment surface and the water tray. Bars represent ± SE.

DISCUSSION

In our study, we confirmed that bats attempted to drink from smooth surfaces, including surfaces similar to wind turbine towers. We also found that when these surfaces were texturized, bats no longer made contact with them, and bats approached the surfaces less frequently when particle density was highest. Based on our findings, it may be possible to design a texture coating that bats show little or no interest in approaching.

The drinking behavior trials revealed that bats were not able to distinguish the smooth metal or smooth painted treatment surfaces from water as they attempted to drink from these treatment surfaces, in some instances repetitively. These findings confirmed that 1) local bat species attempted to drink from smooth metal surfaces (i.e., the surface most similar to water), as shown by Greif and Siemers (2010) with European bat species. Furthermore, while we did not observe eastern red bats attempting to drink at the smooth painted treatment surface in the drinking behavior trials in 2014, we did record them attempting to drink from this treatment surface during the texture trials in 2015 (Fig. 34). In addition, our texture trials also revealed that bats attempted to drink from a curved smooth painted surface similar to a wind turbine tower. Using the high-speed camera, we were able to determine that 7 of the 9 contacts recorded at the curved treatment surface were drinking attempts (Fig. 34). We noted that in these drinking attempts, bats approached the treatment surface with their heads positioned down and with the ventral side of their bodies oriented parallel to the surface. The same approach was also observed when the bats drank at the water tray (n = 12; Fig. 33; Tuttle et al. 2006, Jackrel and Matlack 2010, McAlexander 2013). These combined results support our hypothesis that bats misperceive the smooth surfaces of wind turbine towers to be water, and reinforces the results from previous behavioral studies that have reported drinking attempts at wind turbines (McAlexander 2013).

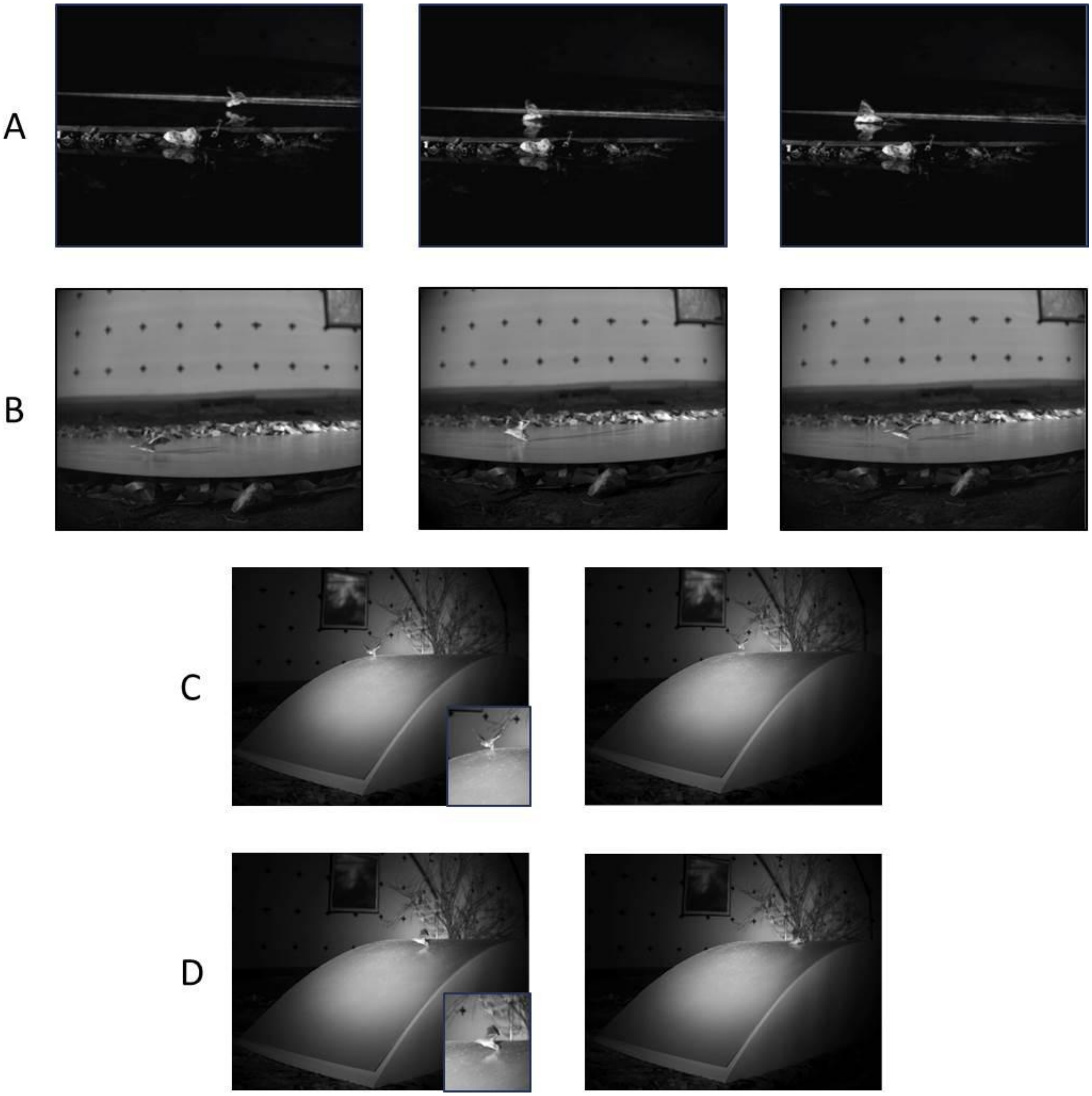


Figure 35. Images from Fastec IL4 camera. **A)** An evening bat drinking from the water tray. **B)** An eastern red bat attempting to drink from the smooth painted treatment surface. **C)** An evening bat attempting to drink from the curved treatment surface making its approach across the length of the treatment surface. **D)** An evening bat attempting to drink from the curved treatment surface with an approach across the width of the treatment surface.

One potential limitation to our experimental trials was that our treatment surfaces were in the horizontal plane rather than in a vertical position like turbine towers bats would encounter in the wild. For the well-being of the bats, water was available in the water tray 24 hours a day, except during the limited time when the experimental trials were conducted. The bats therefore would be seeking water from this horizontal source and not from the vertically placed treatment surfaces. Thus, a 20 minute trial was not enough time for the bats to investigate alternative water sources, and preventing bats from being able to drink from water for longer than 20 minutes may have caused them harm. Moreover, even though we did not directly test bats' capabilities of drinking at vertical surfaces, researchers have observed bats drinking from other smooth, vertical surfaces, for example, stalactites (Cryan and Gorresen 2013). These observations, albeit anecdotal, provide further evidence that bats could misperceive the smooth surfaces of wind turbine towers to be water. Nevertheless, vertical treatment surfaces could be tested in a study, if vertical water was provided 24 hours a day. We therefore recommend this as a future study.

Our texture trials revealed that once surfaces were texturized with paint additives (such as sand grains and woodchips), the bats did not attempt to drink or even make contact with them. In contrast, our appliqué treatment surface did not hinder bats from making contact with the surface. We can only speculate that the bats perceived the areas between the foam strips (i.e., 0.5 m x 1 m smooth painted surfaces) to be large enough for them to attempt to drink. We also noted that at this treatment surface bats altered the direction of their approach to avoid the appliqué strips. We found that bats oriented themselves parallel to the width of the treatment surface instead of the length; the latter was commonly observed with the curved smooth treatment surfaces. These results show that while appliqué would not effectively impede bats from making contact with a smooth surface, they do support our hypothesis that a texture coating (such as a paint additive) could prevent bats from attempting to drink at wind turbine towers.

Another important consideration for an effective texture coating should be that bats quickly recognize that a surface does not provide a resource and, therefore, only spend a short amount of time investigating that surface. Studies have shown that bats make multiple passes while investigating surfaces such as water (Tuttle et al. 2006, Razgour et al. 2010). The number of passes bats make over a particular treatment surface may therefore be used as an indicator of interest. Thus, an effective treatment coating (i.e., a surface that bats have little or no interest in) would be a surface that bats make few passes over. Our texture trials revealed that bats made the fewest passes over the fine texture treatment surface, suggesting that bats showed the least amount of interest in this surface. Based on a study by Yuen (2015), we would have expected that as particle size increased the bats should be able to differentiate between smooth and textured surfaces more effectively and, therefore, would have recorded fewer passes at the coarse textured treatment surface. However, as our addition analysis revealed, increasing gap size between particles was associated with an increase in the number of bat passes. One possible explanation for this increase is that bats could not readily determine whether a surface was textured or not because the numerous small gaps appeared to represent smooth surfaces. For example, a bat may have identified the presence of one or more particles in a pass and none in the subsequent pass. The bats, therefore, may have had to make multiple passes across a surface to confirm whether it was textured or a potential water source. Moreover, the probability of detecting particles during each pass would decrease with increasing gap size, resulting in more passes.

In addition, Yuen (2015) revealed that high frequency bats (bats with typical echolocation frequencies >35 kHz) should be capable of differentiating fine particle surfaces from smooth surfaces. This supports our findings, as the eastern red and evening bats used in our study were both high frequency bats and showed little interest in the fine texture treatment surface. We would have expected bats to behave similarly at the coarse and intermediate textures because they can also differentiate these particles; however, high frequency bats showed more interest in the intermediate and coarse surfaces which had lower particle density. Thus, an effective texture coating for high frequency bats would need to have a high density of particles to ensure gap size is kept to a minimum.

Another limitation of our study was that we were unable to include low frequency bats (bats with typical echolocation frequencies <35 kHz; i.e., hoary and Mexican free-tailed) in our trials. These species may not respond to the treatment surfaces in the same way as eastern red and evening bats. We, therefore, recommend that future studies include both high and low frequency bat species. Nevertheless, Yuen (2015) found that low frequency bat species should have the greatest amount of surface differentiation at treatment surfaces with large particle sizes. This is not surprising as the echolocation calls of hoary bats are designed to detect larger insects at a distance (Barclay 1985). For example, a study showed that a low frequency bat echolocating at 10 kHz would not be able to detect insect wings lengths below 34 mm, whereas a high frequency bat echolocating at 100 kHz could detect wing lengths of 3.4 mm (Houston et al. 2004). Thus, an effective texture coating for multiple species (both high and low frequency bats) would therefore likely need to comprise both fine and coarse particles.

Finally, our study suggested that bats need to be in close proximity (<0.5 m) to a surface to effectively identify a surface texture. To identify large objects, such as trees, on the landscape at a distance, bats may rely on vision rather than echolocation (Boonman et al. 2013). Schnitzler and Stilz (2012) revealed that bats could identify objects 1 to 20 m away using echolocation. An echolocation call at 40 kHz first detected water (smooth surface) at ~20 m, and a tree (textured surface) was detected at ~12m (Schnitzler and Stilz 2012). Thus, these bat species may be able to differentiate a texture coating in a natural setting at a greater distance than we observed in the flight facility. As previously mentioned, bats had access to the water tray 24 hours a day, except when the trials were conducted; as a result, the bats may not have been echolocating when they began their approach because they had learned where the water tray was located. Therefore, the proximity of these passes may be specific to our flight facility setting. For future studies, it may be beneficial to change the location of the water tray each night. Nevertheless, our results demonstrated that the number of passes at close proximity increased with increasing gap size.

Based on our findings, we recommend that a paint additive texture coating be designed that is 1) densely textured (i.e., only small gaps between particles, and 2) contains multiple sized particles. Once such a texture coating has been developed, we recommend behavioral testing with the manufactured surface texture in a flight facility to ensure bats do not exhibit behaviors of interest towards this texture. We then recommend a small-scale implementation of the treatment surface at an operational wind farm to determine the effectiveness of such a texture coating at reducing bat fatalities.

CONCLUSION

This study identified potential textured surface features which could be used to design a texture coating for wind turbine towers that 1) reduces the amount of interest bats show towards the surface, and 2) prevents bats from attempting to drink at the surface. If turbine tower surfaces were effectively texturized, bats may ultimately spend less time within the rotor swept zone. Any reduction in the time bats spend in the rotor swept zone should lead to a reduction in collision risk with rotating blades. Designing and then applying a texture coating to turbine towers, currently operational and in the manufacturing stage, may therefore prove to be a cost-effective strategy for mitigating bat fatalities without hindering renewable energy generation.

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Personal Background

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Education

2009	Diploma, New Haven High School, New Haven, IN
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Experience

2014-Present	Teaching Assistantship, Texas Christian University
2014(May-Aug)	Research Technician, Texas Christian University
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Bienz, C., V. Bennett, and A. Hale. 2016. Surface texture discrimination using synthetic bat echolocation calls: implications for reducing bat fatalities at wind turbines. Michael and Sally McCracken Student Research Symposium. Texas Christian University. Fort Worth, TX.

Bienz, C., V. Bennett, and A. Hale. 2015. Surface texture discrimination using synthetic bat echolocation calls: implications for reducing bat fatalities at wind turbines. 45th North American Society for Bat Research Conference. Monterey, CA.

Bienz, C., P. Zollner, J. Rodkey and C. Bleke. 2013. Testing *Peromyscus* trap response to familiar and unfamiliar conspecific odor cues in Sherman traps. Indiana State Fish and Wildlife Conference. Lafayette, IN.

Bienz, C., P. Zollner, J. Rodkey and C. Bleke. 2013.Testing *Peromyscus* trap response to familiar and unfamiliar conspecific odor cues in Sherman traps. FNR Research Symposium. Purdue University. West Lafayette, IN.

Awards

2016	1st place graduate student poster, Texas Christian University
2015	$500 -1st place student poster for bat conservation, 45th North American Society for Bat Research Conference
2013	$500 – Undergraduate research grant

ABSTRACT

SURFACE TEXTURE DISCRIMINATION BY BATS: IMPLICATIONS FOR REDUCING BAT MORTALITY AT WIND TURBINES

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It has been hypothesized that bats contact wind turbines because turbines are perceived to provide resources. Studies have shown that bats misidentify smooth surfaces to be water and that bats approach turbine towers with the same posture as bats drinking at water. We predict that if tower surfaces were textured, bats would spend less time near the rotor swept zone, thereby reducing collision risk. We conducted behavioral experiments in a flight facility to identify a texture that bats showed little or no interest in approaching. We presented bats with 8 treatment surfaces and recorded contact as well as the number, distance, and timing of passes at each surface. We found that bats did not contact textured surfaces and showed little interest in textured surfaces with a high particle density. These results were used to inform a texture coating that can be applied to turbine towers as mitigation for bat fatalities.