A Meta-Analysis of Bird-Window Collision Solutions

by

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Abstract

North American bird populations are declining and bird-window collisions are a leading cause, resulting in 365 - 988 million bird deaths each year in the U.S. alone. One approach aimed at reducing these collisions is treating windows to reduce reflectiveness. To address the lack of comparisons between window treatments, my goal was to use a meta-analytic approach to evaluate window treatments. Specifically, the objective was to account for the variation between studies and quantify an overall effect of applied treatments, effect and rank of individual treatments, and effect and rank of treatment characteristics. I reviewed the literature following PRISMA guidelines and used meta-analysis to evaluate data across studies. I used rate ratios to compare collision rates of treated windows to clear glass for an overall estimate of effectiveness, as well as estimate for individual treatments and treatments grouped by characteristics. Overall, all treatments included in the study resulted in ~80% reduction in rate of collisions compared to clear glass. Individual treatments that performed best were complete coverage of the window with a UV absorbing and reflecting pattern (CPFilms, Fieldale, Virginia, USA) and complete coverage with white CollidEscape (Janesville, Wisconsin, USA). Assessment of treatment characteristics suggests extensive patterning and contrast are important for bird-window collision solutions to be extremely effective. Application of treatments to existing windows provide a benefit to birds and feasible solutions are available for homes and businesses.

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PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analyses
UV	Ultraviolet

LAY SUMMARY

- Birds collide with windows because their perception differs from humans and they perceive reflection on glass as real rather than glass as an object.
- Many studies have developed treatments for windows to reduce bird-window collisions and tested them in real world settings.
- The objective was to synthesize and compare these treatments using meta-analysis to help identify the most effective options for current application and future development of new treatments.
- Overall, all treatments resulted in ~80% reduction in rate of collisions compared to clear glass.
- Extensive patterning and contrast are important characteristics for extremely effective treatments.
- Application of window treatments will save birds from this human-driven mortality.

INTRODUCTION

North American bird populations have decreased by almost three billion birds (29%) since 1970, due to climate change, habitat loss, agricultural intensification, coastal disturbance, and human-driven mortality (Rosenberg et al. 2019). One major anthropogenic source of this mortality is bird-window collisions (Machtans et al. 2013, Loss et al. 2014b). In the U.S. alone annual mortality due to window collisions is estimated to be 365 - 988 million birds (Loss et al. 2014b). Collisions occur in all seasons and across all groups of birds (Klem 1989, Gelb and Delacretaz 2006, Klem 2009a, Hager and Craig 2014, Klem 2014).

Birds strike windows because they cannot perceive glass. Instead, birds see through glass or see reflections of vegetation or open sky (Klem 1989). This perception problem can easily be addressed by making glass appear as an impassable object and research has already identified many solutions to reduce bird-window collisions. During construction, solutions that can be implemented include reducing glass area, adding design features such as overhangs and awnings, and using non-reflective solidly colored or tinted glass, which can also help LEED (Leadership in Energy & Environmental Design) certify a building (Klem et al. 2004, Klem et al. 2009, USFWS 2016, US Green Building Council 2018). There are additional solutions available for post construction, including retrofitting existing windows and changing their appearance. As solutions have accumulated, research has focused on characteristics of window treatments to optimize reduction of bird collisions, maximize aesthetic qualities, and minimize costs. As a result, there has been a notable effort placed on evaluating materials, including hanging plants, decals, plastic, glass etching, paracord, shades, and adhesive films, and the characteristics of the how these materials are applied, such as amount of coverage and treatment shape (Klem 2009b, Klem and Saenger 2013, Rössler et al. 2015, Mitrus and Zbyryt 2017, Sheppard 2019). Bird of prey silhouettes were once popular, but the effectiveness of bird of prey silhouette treatments has been discussed in literature as poorly effective or ineffective (Brisque et al. 2017, Johnson and Hudson 1976, Klem 1979, Ribeiro and Piratelli 2020). The physiological perception ability of birds has also been an area targeted for knowledge expansion (Håstad and Ödeen 2014). Treatments have been evaluated in terms of birds' physiological perception of the treatments to understand their ability to see contrast between natural scene reflections and human visible, ultraviolet absorbing, and ultraviolet reflecting light (Klem 2009b, Klem and Saenger 2013, Håstad and Ödeen 2014). Although many individual studies have evaluated window treatments, comparisons of these retrofitted solutions in real world settings have been limited mostly to multiple treatments within a study and have lacked the ability to compare between studies.

To address the lack of comparisons between window treatments, my goal was to use a meta-analytic approach to evaluate window treatments. Specifically, the objective was to account for the variation between studies and quantify an overall effect of applied treatments, effect and rank of individual treatments, and effect and rank of treatment characteristics. I expected bird of prey silhouettes to perform poorest. There was high uncertainty a priori about which specific treatments would do best, but based on published literature on the topic, I expected effects to vary by characteristics based on treatment shape, amount of coverage, and how the treatments are perceived by birds.

METHODS

To determine the effectiveness of window treatments overall, individually, and grouped by characteristics, I performed a meta-analysis following the 2020 updated PRISMA guidelines (Page et al. 2021), searching two databases. Google Scholar was searched using (“Marking” OR “decal” OR “film” OR “treatment” OR “bird-safe”) AND (“glass” OR “window”) AND (“bird” OR “avian”) AND (“collision” OR “strike” OR “mortality” OR “mortalities”). Web of Science Core Collection was searched with similar terms, but used the database’s wildcard searching by truncating with an asterisk to indicate all endings of the word were acceptable. The search string used in Web of Science was (("Marking*" OR "decal*" OR "film*" OR "treatment*" OR "bird-safe") AND ("glass" OR "window*") AND ("bird*" OR "avian") AND ("collision*" OR "strike*" OR "mortalit*")). Patents and citations were excluded from both searches. The Google Scholar search resulted in about 323,000 results on June 4th 2021. The software Publish or Parish (Harzig 2007) was used to assist with copying records from Google Scholar. Due to the large number of results, only the first 200 results from Google Scholar were used, when sorted by relevance. The Core Collection in Web of Science search was performed on June 11, 2021 and obtained 35 results. Duplicated records were removed for a combined total of 214 results from Google Scholar and Web of Science. I used literature in "Bird Collisions with Glass: An Annotated Bibliography," (Seewagen and Sheppard 2019) to identify the earliest relevant publications. The first publication in the annotated bibliography that included a solution to bird-window collisions was in 1976. Therefore, I removed records older than 1970, resulting in 212 records from Google Scholar and Web of Science for screening.

The search results were screened by title, abstract, then full publication. First, any records with titles that were obviously irrelevant were removed from further consideration (e.g. avian diseases, DNA analysis), leaving 129 records with the potential to be relevant based on titles. Next, abstracts, introductions, or summaries were read to see if they mentioned bird-window collisions and mitigation, with even the vague mention of mitigation treated as potentially relevant. If a book was inaccessible or lacked an introduction, summary, or abstract the table of contents was read to identify if bird-window collisions and mitigation were discussed in the publication. If the table of contents did not indicate that bird-window collisions and mitigation were included, the publication was removed from further screening. The screen of abstracts, introductions and summaries identified 68 records to be read in full. After being read in full, records were retained for analysis if they reported collision data for a solution applied directly to windows, had clear glass as the control, reported control collision data, and reported duration of control and solution testing. The inclusion criteria were based on application of treatments in real world scenarios, so the effect metric was based on number of collisions over time. Studies were excluded if they used different controls or a study design that yielded incomparable results, such as tunnel testing. Studies were also excluded if they did not clearly report necessary data in English. Of the 68 records, 11 were suitable for analysis.

One of the records in the initial search was the annotated bibliography, "Bird Collisions with Glass: An Annotated Bibliography," by Seewagen and Sheppard (2019). The records in the annotated bibliography were also considered for inclusion in this study. The total number of records in the annotated bibliography was 177. After duplicate records were removed, 141 studies remained. One study was older than 1970 and removed from the screening process. The same screening methodology for the Google Scholar and Web of Science search was used for the annotated bibliography, but the summary in the annotated bibliography was read instead of the abstract. If the annotated bibliography's summary was too short to understand the scope of the record, the publication abstract, summary or introduction was read. All 140 titles were screened for relevancy, and all titles were potentially relevant to the study. Therefore 140 of the annotated bibliography summaries were read. Nine summaries were very short so abstracts were read in addition. A total of 49 of the summaries and abstracts mentioned bird window collisions and solutions. The full version of three studies were inaccessible, and therefore excluded. I read the 46 publications and four studies were usable for analysis.

The original search and the annotated bibliography resulted in a total of 15 studies for analysis. I screened the references of these 15 studies to consider additional publications for analysis. The same screening methodology as the Google Scholar and Web of Science search was used. There were 485 references total. After duplicates and records older than 1970 were removed, there were 174 records for title screening. I read the titles and found 139 to be potentially relevant. Three unpublished manuscripts and 14 other records could not be found for abstract screening and were removed from further consideration. Records that could not be easily found were searched for in Google Scholar and Google with the whole citation as it appeared in the literature cited of the paper, followed by searching with leave one out where the author, year, title, or publisher were left out. This allowed for the record to be located if there was an error recording the citation. If no available digital version was found, it was noted and removed from screening. I read the abstracts and identified 49 records to read fully. None of the records from the references were suited for the analyses, so no studies were added. Thus, a total of 15 studies were available for analyses, some with multiple treatments yielding a total of 36 treatments. All searching and screening data are reported in the PRISMA 2020 flow diagram in Appendix 1 (Page et al. 2021).

Data reported by studies consisted of counts for bird collisions based on evidence left on a window (powder down, feathers, blood, etc.) and dead birds. The number of birds that approached and did not collide were inconsistently reported by studies. Therefore, I used log-transformed rate ratios with number of treatment (window solution tested) collisions per day over number of control (clear glass) collisions per day (Osenberg et al. 1999). I used the *metafor* package in R to calculate effect size and variance (Viechtbauer 2010).

Within the *metafor* package I ran restricted maximum likelihood random and mixed effects models with moderators for author, treatment shape, bird of prey silhouette, pattern coverage, and an additional grouping based on how birds perceive the solutions (Viechtbauer 2010). I tested for author bias using the model to moderate authors. One author in particular, Klem, has done a large portion of research on this topic. The author moderated model compared the treatments from studies done by Klem to the treatments by all other authors. Treatment shapes were grouped into complete film, patterned (with spacing), patterned yet complete coverage, shades, and stripes. The bird of prey silhouette model was moderated into bird of prey silhouettes and other, to compare the bird of prey silhouette treatment to all other treatments. The bird of prey silhouette model allows for a summary of effectiveness of bird of prey silhouettes over multiple studies. Pattern coverage was categorized into full coverage or partial coverage, where full coverage has no open glass present after treatment. Treatment groups based on bird perception categorized treatments as solidly colored, ultraviolet reflective, ultraviolet absorbing, and the combination of ultraviolet reflective and absorbing. Effects coding was used to obtain average effect size for the assigned treatment groups. I used random and mixed effects models because I expected the different treatment groups to have their own mean and variability, due to the difference in how the groups are visualized by birds and function differently to make glass surfaces appear as an unpassable object. The random effects model was used to model between and within treatment variation and to obtain an overall average estimated effect. I converted results from natural log scale back into rate ratios for easier communication. I assessed and reported where necessary the intraclass correlation coefficient (I^2), the R^2, significance ($p < 0.05$), effect sizes, and confidence limits for moderated groups and overall.

RESULTS

The overall model, the restricted maximum likelihood random effects model, indicated a considerable amount of variation between studies rather than within studies (Table 1). The rate ratio effect size was 0.19 (0.14, 0.26; 95% CL; $p < 0.0001$), meaning the treatments overall have ~20% the average collision rate compared to clear glass (treatments have ~80% reduction in rate of collisions compared to clear glass). The individual treatments that performed poorest for collision reduction were Klem’s (2009b) REX20 film where 20% of light was transmitted and

65% of visible light was reflected and bird of prey silhouette decals in the Brisque et al. (2017) and Ribeiro & Piratelli (2020) publications (Figure 1, treatment 6, 22, and 29). The REX20 film is described by the author as having a high reflective quality (Klem 2009b). The three individual treatments that had the best reduction in collisions were Klem's (2009b) application of UV reflective and absorbing stripes for complete film coverage of the glass, both the 5 cm wide reflecting with 2.5 cm wide absorbing and the 2.5 cm wide reflecting with the 5 cm wide absorbing stripes (CPFilms, Fieldale, Virginia, USA), and white CollidEscape (Figure 1; Janesville, Wisconsin, USA).

Consistent with the overall model, the I^2 of the moderated models indicated a considerable amount of variation between studies rather than within studies (Table 1). The bird perception, bird of prey, and treatment shape moderated models explained a low amount of heterogeneity (R^2; Table 1). The other moderated models did not explain any heterogeneity (R^2) and the test for heterogeneity suggests the true effects are heterogeneous in all models (Table 1). All groups in the moderated models had a significant effect, except the bird of prey silhouette group ($p = 0.0518$) (Figure 2). Variation among groups was detected only in the treatment shape, bird of prey, and bird perception models (Table 1). The significance testing between groups within the treatment shape, bird of prey, and bird perception models revealed significance for the following pairs: pattern complete and complete film ($p = 0.0224$), stripes and complete film ($p = 0.0179$), bird of prey and all other treatments ($p = 0.0409$), UV both and UV absorbing ($p = 0.0091$), and UV absorbing and solid ($p = 0.0341$). There was no significant difference in the Author model, indicating that there is not an author bias present ($p = 0.9553$).

In the treatment shape model, shades were the most effective of all groups in the model with a 0.10 (0.02, 0.48; 95% CL, $p = 0.0036$) collision rate compared to clear glass. Shades were followed by stripes and complete coverage of the window surface by pattern (pattern complete). Stripes had a collision rate of 0.12 (0.07, 0.22; 95% CL, $p < 0.0001$) compared to clear glass and pattern complete had a collision rate of 0.12 (0.07, 0.23; 95% CL, $p < 0.0001$) compared to clear glass (Figure 2). The lowest effective group was complete film in the treatment shape model (0.31 [0.19, 0.52; 95% CL; $p < 0.0001$]). In the bird of prey model, the all other treatments group (0.17 [0.13, 0.23; 95% CL; $p < 0.0001$]) was ~2.6 times more effective than the bird of prey silhouette group (0.44 [0.19, 1.01; 95% CL; $p = 0.0518$]). The full coverage and partial coverage groups in the pattern coverage model were not significantly different ($p = 0.7332$). The model estimated the effect of full coverage of a window to be 0.20 (0.13, 0.30; 95% CL; $p < 0.0001$) and partial coverage to be 0.18 (0.12, 0.28; 95% CL; $p < 0.0001$) when treatments are compared to clear glass. In the bird perception model the combination of UV reflective and absorbing performed best, resulting in 0.12 (0.07, 0.23; 95% CL; $p < 0.0001$) collisions compared to clear class, but the UV absorbing treatment alone performed poorest of all groups in the model (0.37 [0.21, 0.65; 95% CL; $p = 0.0005$]; Figure 2).

DISCUSSION

Based on the overall model, treatments resulted in ~20% the rate of collisions compared to the rate with clear glass, meaning ~80% reduction in collisions. While nearly every treatment was effective at reducing collisions, treatments varied in effectiveness both individually and by characteristics, making some options better than others for reducing collisions. Overall, the results suggest extensive patterning and contrast are important in making glass appear impassable to birds.

The results indicate that complete patterning of glass was superior to both spaced patterning and compete coverage for reducing bird-window collisions. The treatment shape model results, when combined with the pattern coverage model, indicate that extensive patterning is more important than complete coverage. In addition, the three best performing treatments in this study all had extensive patterning, but only two had complete coverage. Recent work has focused on partial window coverage, as it is perceived as more acceptable to the public (Rössler et al. 2015, Sheppard 2019). The pattern coverage model indicated partial coverage to be similar to full coverage, but the treatment shapes model found complete coverage with a pattern to be ~2 times more effective than a spaced patterned treatment. Partial coverage of windows was effective, but extensive patterning provides greater benefits for birds and should be considered more thoroughly both in implementation and development of new solutions.

The results also suggest patterns that create strong contrast are effective for reducing collisions and the conclusions are supported by avian sensory ecology. In the bird perception model, the combination of UV absorbing and reflecting materials performed best. In the treatment shape model, complete coverage with a pattern performed ~2.5 times better than complete coverage with a single film. One other study also found improvements by contrasting UV absorbing and reflecting film (Sheppard 2019; CPFilms, Fieldale, Virginia, USA). Considering avian sensory ecology, birds have lower contrast sensitivity than humans, meaning they are less able to discriminate between two objects with different luminance (Ghim and Hodos 2006), which may explain why contrasted solutions performed better. In addition, birds vary in their ability to perceive ultraviolet light (Ödeen and Håstad 2013) and this differential ability may also explain why contrast performed better in the model than UV reflecting or absorbing materials alone. The results and avian visual abilities suggest strong contrast, especially when using UV products, is an important treatment quality for bird-window collision solutions.

Overall, while the models supported the use of UV treatments to reduce collisions, the use of UV applications have limitations. UV products are dependent on receiving sunlight to reflect or absorb UV radiation and are not equally effective during all parts of the day or all seasons due to variability in light intensity (Håstad and Ödeen 2014). Also, UV coatings may be reflective and increase collisions (Klem and Saenger 2013, Kummer et al. 2016). In this study, some treatments testing UV absorbing films reported reflectance of visible light, which may increase reflectivity and explain higher collision rates for UV absorbing and complete coverage with a single film (Klem 2009b). The ability of birds to perceive UV light varies even within closely related taxa and further complicates the use of UV products (Ödeen et al. 2011, Ödeen and Håstad 2013). Clades known to see UV are Psittaciformes, Trogoniformes, Momotidae, Pteroclidiformes, and some within Passeriformes and Charadriiformes (Ödeen et al. 2009, Ödeen et al. 2011, Ödeen and Håstad 2013, Ödeen and Håstad 2014). Other avian orders and families do not see UV (Ödeen and Håstad 2013, Ödeen and Håstad 2014). Birds able to perceive UV may see UV markings that absorb at least 50% UV when glass has a reflected natural background, but birds unable to see UV are unlikely to see the treatments (Håstad and Ödeen 2014). More variable reflections such as reflections of trees make seeing the UV treatments more difficult, compared to open sky or clouds (Håstad and Ödeen 2014). UV window solutions can be an effective option, but the amount of light on the window and reflective quality of the product should be considered, as well as UV perceptive ability by species affected in the area.

Notably, I was unable to analyze all known solutions to window collisions as some methods have not been evaluated in the literature and others have data that are not compatible with the effect metric. Additionally, the models had considerable residual heterogeneity (maximum R^2 of 14.56%, Table 1), indicating there is variability in effectiveness not explained by moderated treatment groups. Based on the variable nature of the treatments, it is expected for residual heterogeneity to be significant. However, future research can investigate additional treatment characteristics that influence effectiveness to better explain heterogeneity and further refine our knowledge of relative effectiveness of treatments. Specifically, I was unable to obtain estimates for finely detailed characteristics of partial coverage, and due to the popularity of these treatments, more needs to be known about characteristics and mechanisms. In addition, in studies testing spacing patterns, orientation and spacing were more important than the percentage of glass surface covered and the size of treatments, but unknowns still exist about interactions between orientation and spacing (Rössler et al. 2015, Sheppard 2019). The recent research on optimizing patterns could be synthesized in greater specificity to reveal if there are important characteristics and define future research and development directions.

It would also be beneficial for more publications to report real world application of solutions. Documenting real world use of treatments will provide more data, options, and help inform how solutions perform, but need to be standardized in methods to improve reliability and comparability. Some guidelines and manuals have been created that can guide researchers and community scientists (Loss et al. 2014a, Brown et al. 2020). Improving availability of results as well as understanding relative effectiveness of characteristics are important for solving this global problem.

Individually, full coverage with alternating UV reflecting and absorbing and the extensive patterning of white CollidEscape (Janesville, Wisconsin, USA) were best at preventing collisions. Based on effectiveness, these are ideal choices, but finding a suitable solution is not based solely on collision reduction. Currently, commercially available, highly effective options can be cost prohibitive, which serve as a barrier to application. Furthermore, some products are unavailable to the public, difficult to apply, require frequent replacements, or have poor aesthetics. In choosing a window treatment, these other factors must be balanced with the objective of optimizing effectiveness. However, nearly all treatments are better than no treatments. To implement solutions on the scale needed to protect birds, these tradeoffs need to be reduced either through existing treatments, or in the development of new ones. In addition, further research should be performed to discover public knowledge and perception of bird-window collisions and treatments, as well as willingness to pay in order to identify barriers and potential solutions. Other important research and community science projects have investigated exactly where collisions occur, identifying buildings of greatest need (Georgia Audubon n.d., New York City Audubon n.d.). This type of information is important to help prioritize solution implementation, as well as serve as outreach. The application of window treatments will reduce bird-window collision mortality and lessen one impact of human development on birds.

The results reveal that small efforts to cover windows can have a big impact. Based on recent collision estimates, an 80% drop in collisions would save 292 - 790 million birds per year in the U.S. alone (Loss et al. 2014b). The results provide specific options that can be implemented or serve as a starting point to understand relative effectiveness and identify effective characteristics, specifically extensive patterning and contrast, especially for structures that have already been built. Solutions can and should be applied in homes and businesses to reduce the unintentional harm our windows pose. Bird-window collisions are the second largest human-caused mortality, but they do not have to be (Loss et al. 2015).

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TABLES

Table 1. Results for models evaluating window treatments for bird-window collisions. Overall model is a random effects model; the other models are moderated. Model summaries include I^2 and a test for heterogeneity for all models and in moderated models the R^2 and significance test between groups. The test for heterogeneity in moderated models is residual, testing variability not accounted for by moderators.

Model	R^2 (%)	I^2 (%)	Test for Heterogeneity (*p*)	Test of Moderators (*p*)
Overall	-	88.58	<0.001	-
Author Test	0	87.78	<0.001	0.9553
Bird Perception	14.56	85.71	<0.001	0.0526
Pattern Coverage	0	87.95	<0.001	0.7332
Bird of Prey	7.04	86.46	<0.001	0.4090
Treatment Shape	12.97	85.15	<0.001	0.0495

FIGURES

Figure 1

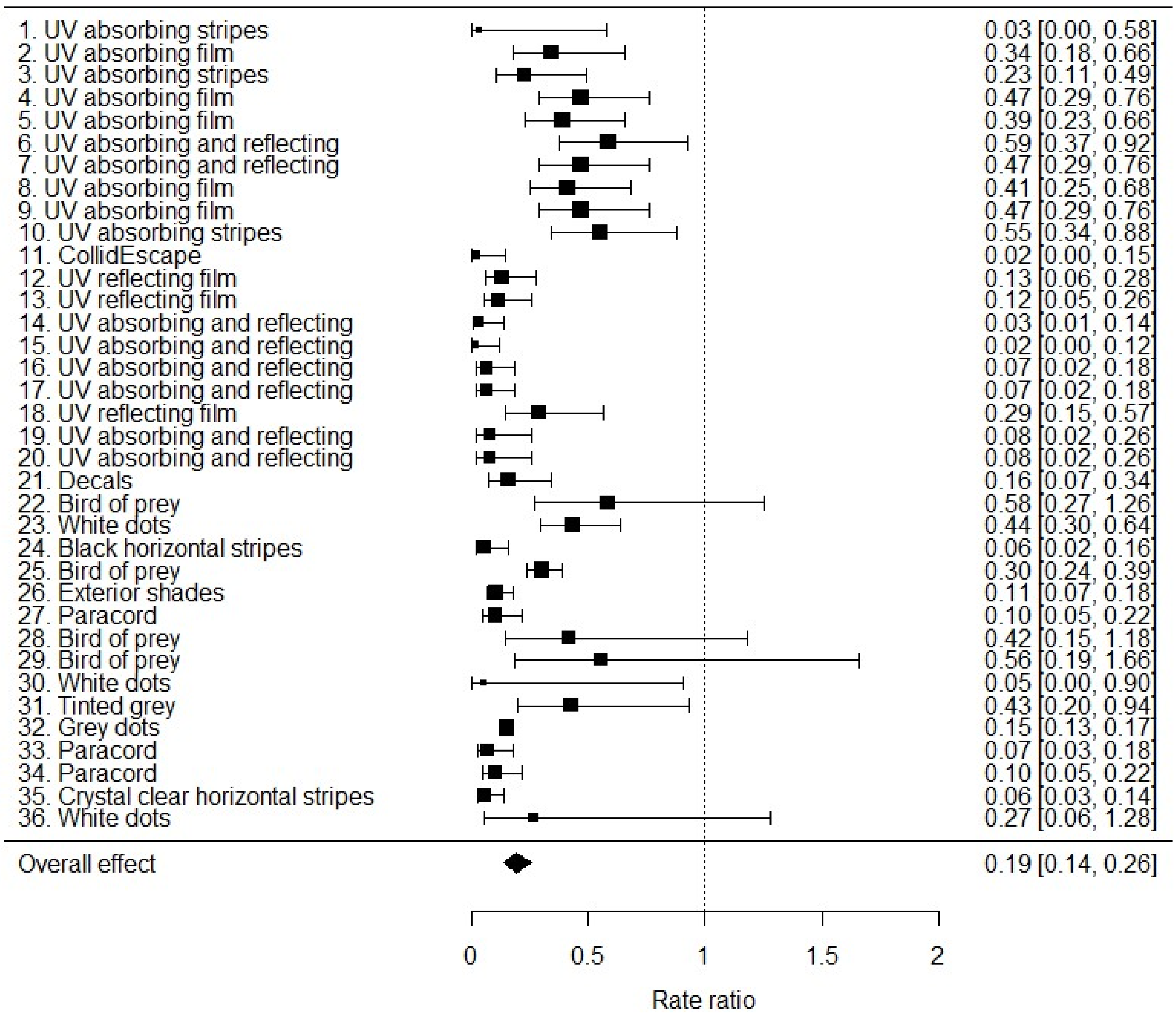


Figure 1. Forest plot of random effects model with each treatment's estimated rate of bird collisions compared to clear glass with 95% CL. Each estimate is labeled with a general description and the treatment number in this study. The dashed vertical line corresponds to no effect. Treatments closer to zero are more effective at reducing bird-window collisions.

Figure 2

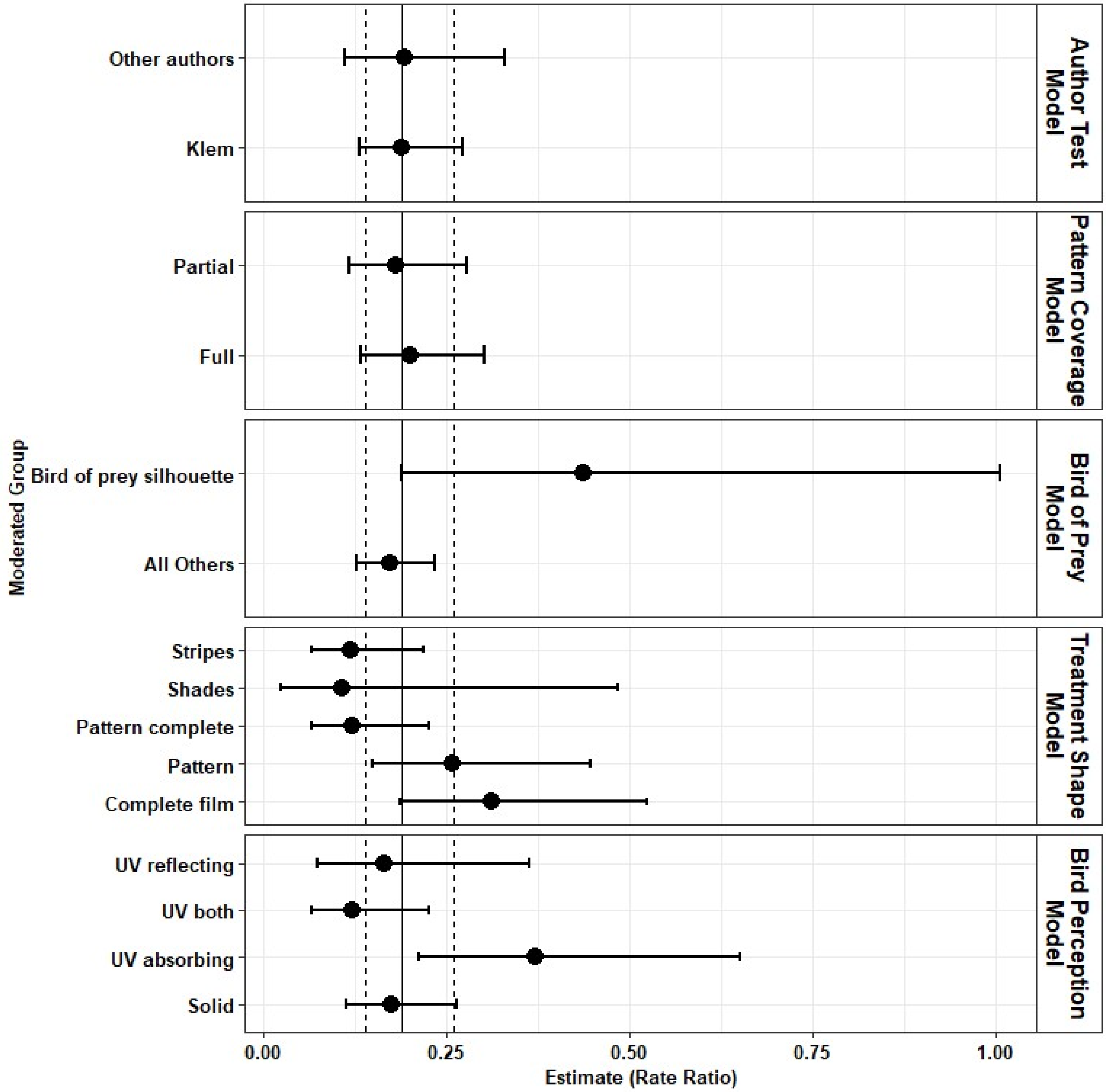
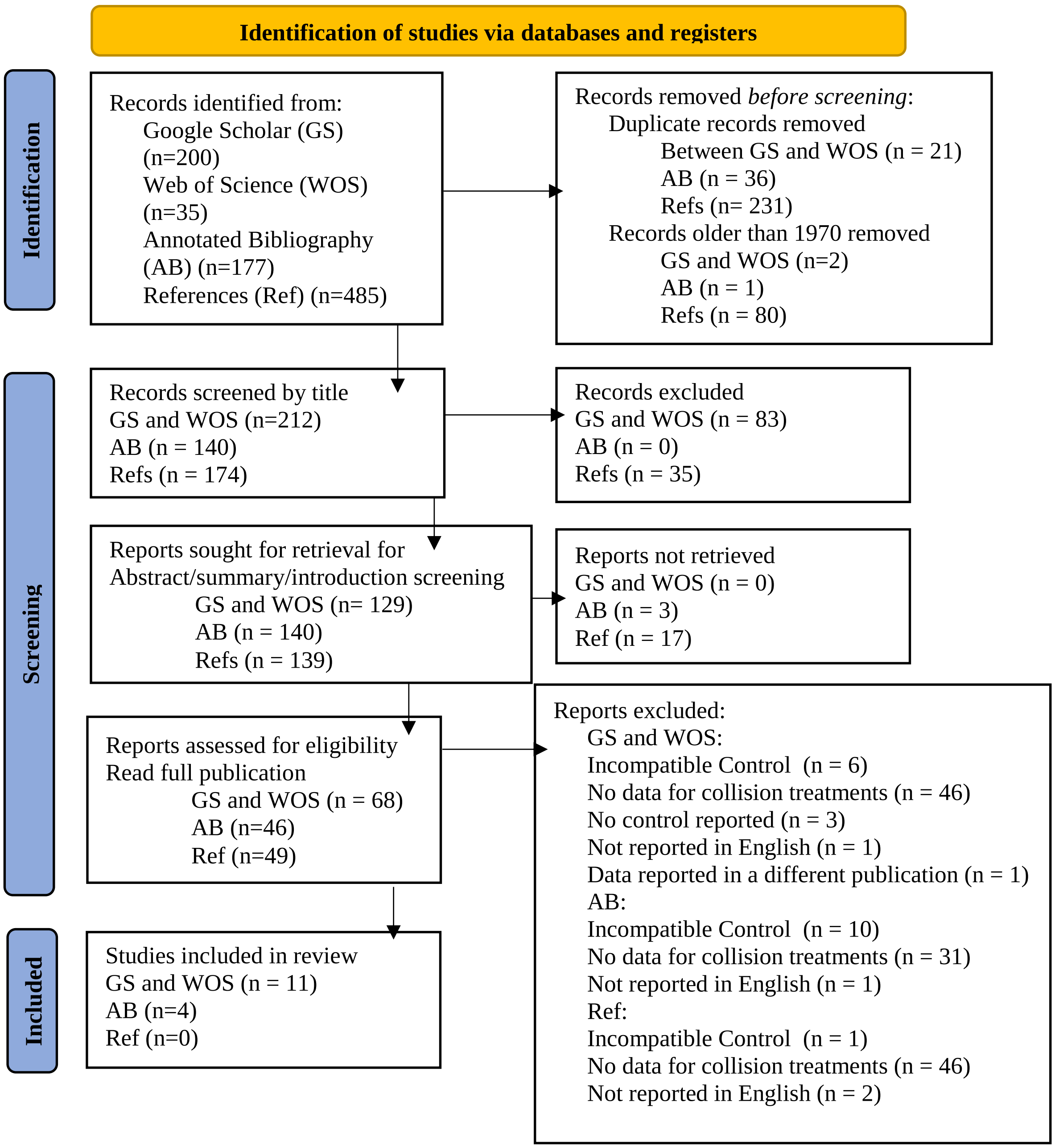


Figure 2. Estimated rate of bird collisions compared to clear glass with 95% CL for all groups in moderated models. The overall model rate ratio estimate is represented by the vertical solid line and the vertical dashed lines indicate 95% CL. Estimates closer to zero are more effective at reducing collisions.

Appendix 1. PRISMA 2020 flow diagram.



From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

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