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Effectiveness of light-reflecting devices: A systematic reanalysis of animal-vehicle collision data

Falko Brieger[a,*], Robert Hagen[a], Daniela Vetter[b], Carsten F. Dormann[c], Ilse Storch[b]

[a] Forest Research Institute of Baden-Württemberg, Wildlife Ecology Division, Wonnhaldestr. 4, 79100 Freiburg, Germany
[b] Freiburg University, Chair of Wildlife Ecology and Management, Tennenbacher Straße 4, 79106 Freiburg, Germany
[c] Freiburg University, Department of Biometry and Environmental System Analysis, Tennenbacher Straße 4, 79106 Freiburg, Germany

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ABSTRACT

Every year, approximately 500 human fatalities occur due to animal-vehicle collisions in the United States and Europe. Especially heavy-bodied animals affect road safety. For more than 50 years, light-reflecting devices such as wildlife warning reflectors have been employed to alert animals to traffic when crossing roads during twilight and night. Numerous studies addressed the effectiveness of light-reflecting devices in reducing collisions with animals in past decades, but yielded contradictory results. In this study, we conducted a systematic literature review to investigate whether light-reflecting devices contribute to an effective prevention of animal-vehicle collisions. We reviewed 53 references and reanalyzed original data of animal-vehicle collisions with meta-analytical methods. We calculated an effect size based on the annual number of animal-vehicle collisions per kilometer of road to compare segments with and without the installation of light-reflecting devices for 185 roads in Europe and North America. Our results indicate that light-reflecting devices did not significantly reduce the number of animal-vehicle collisions. However, we observed considerable differences of effect sizes with respect to study duration, study design, and country. Our results suggest that length of the road segment studied, study duration, study design and public attitude (preconception) to the functioning of devices may affect whether the documented number of animal-vehicle collisions in- or decrease and might in turn influence whether results obtained were published.

1. Introduction

Worldwide, 750 million vehicles are estimated to travel on 50 million km of roads (van der Ree et al., 2011). As the habitats of many wildlife species are transected by roads, essentially every moving terrestrial species is affected by animal-vehicle collisions (AVCs) (Lima et al., 2014; Spellerberg, 1998; Trombulak and Frissell, 2000). Research into AVCs has focused on species which either pose a threat to human safety or whose populations are seriously impacted by roads (Fahrig and Rytwinski, 2009; Huijser et al., 2009; Langbein et al., 2011; Romin and Bissonette, 1996). This focus has resulted in detailed information about the temporal dynamic of AVCs for species that are abundant and exceed a certain body size, in particular many ungulate species.

Within ungulates, the majority of vehicle collisions happen with cervids (i.e. deer [Cervidae]; Romin and Bissonette, 1996). Bruinderink and Hazebroek (1996) estimated around 500,000 deer were killed by vehicles each year in Europe, and Conover et al. (1995) calculated more than one million deer-vehicle collisions each year in the USA. The daily and annual pattern of collisions is well documented for cervids (e.g. Bruinderink and Hazebroek, 1996; Gulen et al., 2006; Steiner et al., 2014; Thurfjell et al., 2015). Steiner et al. (2014) showed for six cervids that the seasonal pattern of deer-vehicle collisions varies among and within species. From a road safety perspective, the risk of collisions with large terrestrial animals depends on a broad range of factors, including traffic volume, animal population density, response time of the driver, speed, course and width of the road, surrounding vegetation and habitats transected (Langbein et al., 2011; Ng et al., 2008; Roedenbeck, 2007; Romin and Bissonette, 1996; Underhill, 2002). When road systems separate habitat types used for cover, feeding or breeding, the risk of AVCs is likely to increase (Coffin, 2007; Fahrig and Rytwinski, 2009; Gunson et al., 2011; Lima et al., 2014). For example, it is assumed that terrestrial animals are likely to cross roads during

* Corresponding author.
E-mail addresses: falko.brieger@forst.bwl.de (F. Brieger), robert.hagen@forst.bwl.de (R. Hagen), daniela.vetter@wildlife.uni-freiburg.de (D. Vetter), carsten.dormann@biom.uni-freiburg.de (C.F. Dormann), ilse.storch@wildlife.uni-freiburg.de (I. Storch).

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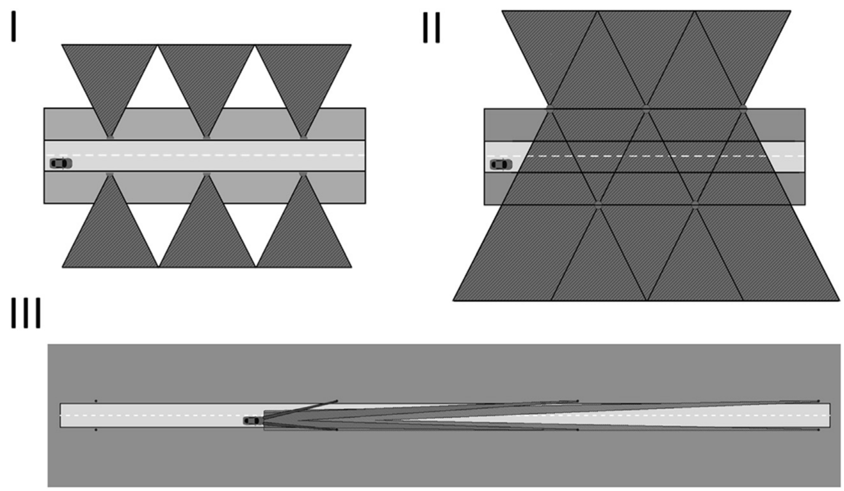

Fig. 1. Concepts of light-reflecting devices in Europe (I, III) and North America (I, II). Concept I demonstrates light reflections of prism reflectors in 90° into the adjacent street area. Concept II displays an installation of prism reflectors where light is reflected in both directions, into the adjacent area and into the middle of the road. Concept III represents the functionality of semicircle reflectors with retro-reflective foil. This device reflects the light of approaching vehicles in a range of maximum 1.5° back to the light source (Schilderwerk Beutha, 2016). Small black points represent guiding posts in 50 m distances. The dimensions in concept III are true to scale with respect to the German street system.

foraging and mating season. Therefore, an ideal solution to reduce the risk of AVCs should simultaneously minimize the impact on the natural movement pattern of the animals affected (Langbein et al., 2011; Putman, 1997; Seiler and Helldin, 2006).

Light-reflecting devices (LRDs) are considered a promising tool to reduce the number of AVCs. These are specifically designed mirrors or warning reflectors ('cat's eyes' [Supplementary data Figs. A & B]) mounted on posts along the side of roads, scattering the headlight of cars onto the roadside, thereby possibly alerting cervids earlier of approaching vehicles (Gladfelter, 1984; Schafer and Penland, 1985; Schwabe and Schuhmann, 2002). The manufacturers of such devices claim that an animal will respond to the reflected light either with flight or increased awareness of approaching vehicles (cf. Schafer and Penland 1985; Zacks 1986; Grenier 2002; D'Angelo et al., 2006). Hence, LRDs are common and frequently used to reduce or prevent AVCs since more than 50 years (Bruinderink and Hazebroek, 1996; Iuell et al., 2003; Nettles, 1965; Ueckermann, 1984).

The first LRD called "Van de Ree mirrors" were developed in the 1950s in the Netherlands (Gilbert, 1982; Nettles, 1965), and in the 1960s some other devices were developed including the Swareflex Wildlife Reflector (Rudelstorfer and Schwab, 1975; Ueckermann, 1984). Until today, several devices have been constructed which reflect the red, green, blue, orange or the whole spectrum of the headlight (Sivic and Sielecki, 2001; Zivny, 1975). LRDs are characterized by different shapes and consist of different materials including steel, prism-plates surrounded by plastic or mirrors, which affects the way how the headlight of an approaching vehicle is reflected. Further, even how each device is mounted along the roadside might differ (Fig. 1). Habituation to the light stimulus of LRDs is a critique that is regularly addressed in scientific publications and was confirmed by Ujvári et al. (1998). More recently, LRDs have been combined with acoustic devices to increase the stimulus for animals along the sides of roads (Steiner et al., 2014).

To date, numerous studies have been conducted to test whether LRDs contribute to a decrease in AVCs, with equivocal findings. Success of LRDs was detected by Gladfelter (1984), Grenier (2002), Schafer and Penland (1985), and Schwabe and Schuhmann (2002), while other studies found no evidence that LRDs affect either the number of collisions (Gilbert, 1982; Reeve and Anderson, 1993; Rogers and Premo, 2004; Sielecki, 2010) or the behavior of the animal (Ujvári et al., 1998; D'Angelo et al., 2006; Ramp and Croft, 2006). Romin and Bissonette (1996) reasoned that claimed success of LRDs is based on opinion, rather than documented changes in annual AVCs, and join the common criticism of reflector studies for having insufficient sample sizes. Differences in findings can also be attributed to the overall variance in AVCs, which is well-documented for deer-vehicle collisions in North America (Gulen et al., 2006; Rogers and Premo, 2004; Romin and Bissonette, 1996). Moreover, most of the studies investigating the effectiveness of LRDs are characterized by "a poor study design" (Roedenbeck, 2007, p. 38), which limits the explanatory power of single studies or road segments (Danielson and Hubbard, 1998). Nevertheless, for more than 50 years LRDs have been sold by manufacturers and installed worldwide along roads in the belief that animals show a behavioral response yielding lower number of AVCs (Iuell et al., 2003; Nettles, 1965).

To our knowledge, we present the first systematic literature review on the effectiveness of all vehicle headlight-reflecting devices in reducing the number of animal-vehicle collisions. We conducted a meta-analysis, a statistical method, which facilitates summarizing the research results from multiple individual studies in an objective way (Koricheva et al., 2013; Vetter et al., 2013).

1.1. Hypotheses

Light-reflecting devices are supposed to induce a reduction in animal-vehicle collisions (c.f. Schilderwerk Beutha, 2016; Gilbert, 1982; Zacks, 1985). Thus, we expect that a reanalysis of all available data about AVCs for the time period 1962–2013 will reveal an overall reduced number of AVCs per year and kilometer after the installation of LRDs. Therefore, we predict that the reduction in AVCs does not depend on the study duration or the length of the road segment. Additionally, based on the principle of light reflection, we hypothesize that the devices only reduce AVCs effectively during night and twilight (Langbein et al., 2011; Rogers and Premo, 2004).

Romin and Bissonette (1996), Rogers and Premo (2004) and Gulen et al. (2006) pointed out that AVCs show inter-annual variation. We expect either a negative value for the temporal autocorrelation for a time lag of one year when the annual number of AVCs per kilometer at year t affects the annual number of AVCs per kilometer at year $t+1$ or a value approaching zero when the annual number of AVCs per kilometer did not depend on the number of