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

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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

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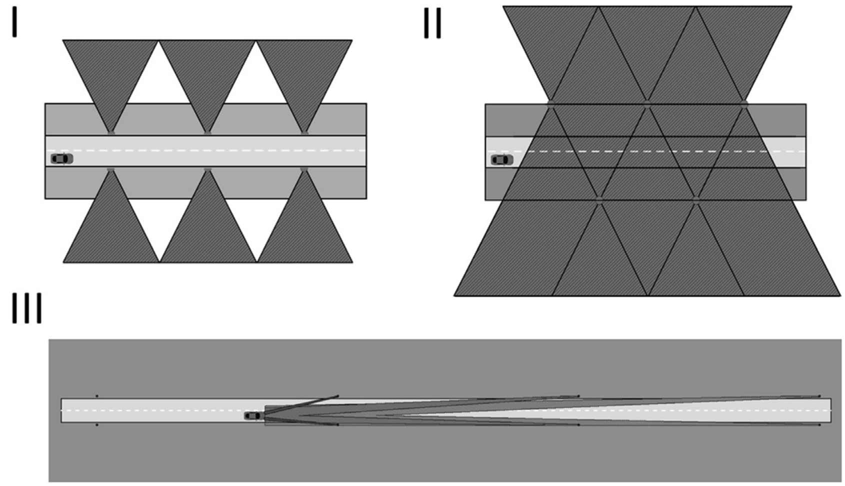

Fig. 1. Concepts of light-reflecting devices in Europe (I, III) and North America (I, II). Concept I demonstrates light reflections of prism reflectors in 90° into the adjacent street area. Concept II displays an installation of prism reflectors where light is reflected in both directions, into the adjacent 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

AVCs of the previous year. Further, we predict that the temporal autocorrelation does not depend on the length of the road segment.

Many studies are characterized by study designs without proper control (Roedenbeck, 2007). We expect that road segments with (the ideal) before-after/control-impact (BACI) design will differ from other designs with respect to conclusions about the effectiveness of LRDs in reducing AVCs.

According to Romin and Bissonette (1996), reported success of light-reflecting devices in reducing AVCs might be based on public attitude. When attitude towards LRDs differs in time and space, we expect a publication bias especially for results presented in newspapers or magazines. This publication bias might cause different conclusions regarding the effectiveness of LRDs in reducing AVCs according to a specific decade or country.

2. Data and methods

2.1. Data

We undertook a systematic literature review (Vetter et al., 2013), aggregating all available information about the potential of LRDs to affect the number of AVCs. We did not restrict our search to a specific taxon or time span. The search procedure was based on a breadth-first search between November 2014-July 2015 using "Google" and "Google Scholar". Key words used included "wildlife warning reflector", "mirror", names of manufacturers, and "report" for each language considered (Danish, Dutch, English, Finish, French, German, Italian, Norwegian, Spanish and Swedish).

We scanned the first 100 results of each conducted search and checked if the findings were relevant for our database based on whether the article 1) contained the words "reflector" or "mirror" in the abstract or introduction, 2) provided data about AVCs or the behavior of animals, 3) provided information on study duration in years and length of the road segment studied. If the authors did not provide all necessary information for our study, we contacted them directly and asked for the missing data. In addition, we checked the cited references of all articles we had found by our breadth-first search and identified additional relevant referenced articles.

We chose "road segment" as the basic unit of analysis. To characterize the road segments in our database in more detail, we first documented the manufacturer of the device together with the reflected light spectrum. Second, we checked whether additional information about the road segment was provided, e.g., habitat types transected, course of the road, speed limit or average speed, daily traffic volume, road density or type of road. Third, we extracted the date when devices were installed along road segments, spacing between devices, distance of devices to road, information on controls of correct functioning of devices and information on time of day of carcass find. When LRDs were installed several times, we used the date of first installation. Fourth, we collected information about type of publication (scientific publication, report, thesis or other, such as articles from magazines, newspapers or manufacturers), and publisher of study (government, university, scientific journal, manufacturer or other, like hunting magazines, newspapers or insurance companies). Fifth, we documented species and family of the carcass (e.g. roe deer [*Capreolus capreolus]*, Cervidae). Finally, we assigned each road segment to one of the following study designs (Roedenbeck, 2007): Before-After (BA: comparison of AVC during a period before installation of LRDs with a period after their installation), Control-Impact (CI: comparison of two road segments, one with and one without LRDs), or Before-After-Control-Impact (BACI: a BA design for two road segments, while LRDs were only installed at one road segment; this allows correction for temporal trends in AVCs independent of the reflectors, e.g. due to changes in traffic, larger cervid population sizes and so forth). We excluded references that simultaneously tested more than one mitigation measure to avoid confounding.

2.2. Methods

First, for each road segment, we calculated the number of AVCs per kilometer and year. If the date of installation (i.e. month) was not provided, we omitted the number of collisions for that year. To aggregate and compare results of different road segments, we applied the metric of Hedges and Olkin (1985). It calculates a standardized mean difference:

$$d = (Y_1 - Y_2) / \sqrt{\frac{(n_1-1)*s_1^2+(n_2-1)*s_2^2}{(n_1+n_2)-2}} \qquad (1)$$

$$\text{with} \quad s_i^2 = 1/(n_i-1) * \sum_j \left(y_{i,j} - Y_i\right)^2$$

Y_1–mean number of AVC with treatment; Y_2–mean number of AVC without treatment; n_1–number of data points with treatment (i.e. years); n_2–number of data points without treatment; s_1–standard deviation within each group with treatment; s_2–standard deviation within each group without treatment; $y_{i,j}$–the annual number of AVCs with $i = 1, 2$; $j = 1, 2, \ldots, n_i$. The term $(n_1 + n_2)$ must result in values greater than two, which means that the overall study duration has to be at least two years.

We calculated *d*, the effect size for each road segment when the study design was equal to BA or CI. For BACI we calculated *d* for each design part (BA and CI) separately and i) generated the mean of both, when the control segment did not include the time before the LRDs were installed at the road segment with BA design, or ii) computed the difference in both parts in the other case. When a reference reported samples taken in an unbalanced study design (for instance data on one road segment without LRD and two segments with LRDs – BAA) the values of the underrepresented part [B] were replicated. For every road segment, the effect size *d* is multiplied by:

$$J = 1 - 3/(4*(n_1+n_2-2)-1) \qquad (2)$$

to account for the small sample size (n_1, n_2) (Koricheva et al., 2013). The result of *d* is called *d'* with its estimated variance compared to Koricheva et al. (2013):

$$v_{d'} = \frac{n_1+n_2}{n_1*n_2} + \frac{d'^2}{2(n_1+n_2)} \qquad (3)$$

We quantified heterogeneity between road segments with effect size *d'* by calculating I^2 a capable measure for consistency between road segments (Higgins and Thompson, 2002; Higgins et al., 2003).

To include data on AVCs where the study duration was shorter than two years or authors have been aggregated annual AVC numbers to a mean AVC value per road segment ($n_1 + n_2 <= 2$ [cf. Eq. (1)]), we computed the collision ratio (*CR*):

$$CR = Y_1 - Y_2 / MAX(Y_1, Y_2) \qquad (4)$$

$CR \in [-1, 1]$, Y_1–mean number of AVC with treatment; Y_2–mean number of AVC without treatment. *CR* is equal to −1 when AVCs were reduced by 100%, it is equal to zero when no reduction in AVCs took place and it is larger than zero when the number of AVCs increased (for instance a value of 1 means that the rate of AVCs increased by 100%).

We used the metafor package (Viechtbauer, 2010) to locate temporal variability in the effect size *d'* by using forest plots. Additional, a funnel plot was performed to test for publication bias in our meta-analysis.

We quantified temporal autocorrelation to test if variation occurs in the AVC data. We fixed the time series for road segments with data points more than eight years before installation of LRDs and calculated the temporal autocorrelation for the following year with respect to the length of the road segments.

Statistical models of effect sizes were violating the assumption of normal distribution. We hence resorted to non-parametric tests (in particular Mann-Whitney U-test and Kruskal-Wallis-test) and non-parametric correlations. To correct for multiple testing, we used Bonferroni correction. Statistical calculations were carried out in R version 3.0.3 (R Development Core Team, 2014).

3. Results

3.1. Literature search

Our literature search yielded 53 accessible references with information on light-reflecting devices (Table 1), and additional 37 references (Table 2), to which we had no access. We accessed 36 references directly via our literature search, 16 references indirectly within reference lists of other authors and one reference through the authors. We could not consider 10 of 53 references for our analysis: in six references the impact of LRDs on wildlife was tested by focusing on animal behavior and no data on AVCs were provided (Table 1, reference no. 4, 14, 16, 26, 48, and 49), three references were excluded, because they did not provide precise data on AVCs and one further reference was omitted that tested two LRDs simultaneously (cf. Table 1, reference 10, 18, 41, and 47). Two references investigated data on AVCs as well as animal behavior (cf. Table 1, reference 8, 50), of which we used data on AVCs. In the end, 43 of 53 references provided data about the annual number of AVCs per year.

In 31 of 43 references, data on AVCs were provided directly in the references, in 11 of 43 references, we received data on AVCs by contacting the responsible author and finally, one of 43 references contained information to AVCs in the reference and its associated web pages. 23 of 43 references listed data on AVCs for all road segments, whereas in 8 references, data on AVCs were usable for only part of the road segments, and 12 references reported only mean AVCs values. The distribution by country was as follows: USA (14 references), Germany (11), Austria (5), Canada (4), Great Britain, Italy and Netherlands (2 each), and Canada/USA, France and Norway (1 each). Information on the LRDs was missing regarding manufacturer (6 references), reflected light spectrum (10), the date when devices were installed (4), the time of day the AVCs took place (23) and information about the correct functioning of the devices (29) [Supplementary data Table A]). The installation year of LRDs ranged for all road segments from 1963 to 2013 with a maximum number of installations in the late 1990s (Supplementary data Fig. C).

For the total of 43 references, the data set contained information on AVCs for 365 road segments. For 185 road segments we were able to calculate the effect size *d*'. We calculated a supplemented collision ratio *CR* for 359 road segments and, for six road segments, neither the effect size *d*' nor the collision ratio *CR* could be calculated. Additionally, we created a reduced data set with all road segments that listed detailed data on AVCs separated by day and twilight/night (N = 37) to test whether AVCs were reduced at twilight or night after the installation of LRDs.

3.2. Meta-analysis

Road segments of group B (long-term studies) with effect size *d*' (N = 185) were characterized by reported annual AVC numbers, a collision ratio *CR* and a study duration more than two years (study duration: mean = 11.79 years, SD = 6.50 years) as well as a length of road segments with range between 0.16 km and 14.5 km (mean = 2.38 km, SD = 2.14 km). Additionally, road segments of group A consisted of a collision ratio *CR* but no effect size *d*' (N = 174). Those were characterized either by a study duration shorter or equal to two years (i.e. short-term studies) or aggregated annual AVC numbers to a mean AVC number per road segment (study duration: mean = 4.41 years), and the length of road segments ranged between 0.1 km and 16 km (mean = 2.08 km).

Based on random-effects model, the forest plot for all road segments with effect size *d*' revealed no significant summarized effect of light-reflecting devices on the trend in reducing animal-vehicle collisions (−0.50, 95% CI −1.01, 0.01 [Fig. 2]).

Furthermore, we observed distinct disparities in the collision ratio *CR* (Eq. (4)) for road segments of group B (long-term studies) compared to road segments of group A, i.e. short-term studies or mean annual AVC numbers. While group A displayed a reduction of AVCs after installation of LRDs (mean = −0.40, SD = 0.57), long-term studies show no alteration in AVCs (mean = 0.00, SD = 0.64 [Fig. 3]). The Mann-Whitney *U* test confirmed significant differences in the effect size *d*' between both groups (W = 10096.5, $p < 0.001$). The Spearman rank correlation test revealed differences according to the effect size *d*' depending on the length of the road segment (S = 463549, $p < 0.001$, rho 0.561) as well as on the study duration (S = 802850, $p = 0.001$, rho 0.239). The Mann-Whitney *U* test revealed no significant differences in the effect size *d*' between daytime and nighttime (V = 27, $p = 0.636$).

Time series of AVCs without any light-reflecting device showed no temporal autocorrelation (-0.036 for a lag of 1 year [Fig. 4 A]). Furthermore, there was no significant effect for road segment length equipped with LRDs on temporal autocorrelation of AVC at lag 1 (Fig. 4 B): the application of a linear model revealed the following estimate for the trend with slope = 0.025, $p = 0.093$.

The percentage of BACI study design was low (5%, 9 road segments), while the inferior before-after design dominated (77%, 143 road segments). The Kruskal-Wallis test revealed significant differences in the effect size *d*' according to the applied study design (Kruskal-Wallis test, $\chi^2 = 14.1733$, df = 2, $p < 0.001$). The Mann-Whitney *U* test uncovered significant differences between BA design (N = 143, mean = −0.42, SD = 2.01) and CI design (N = 33, mean = −0.68, SD = 0.80; [W = 3116, $p = 0.012$]) and BA and BACI design (N = 9, mean = −7.10, SD = 12.87; [W = 990, $p = 0.021$]) and no differences in effect size *d*' between CI and BACI design (W = 188, $p = 0.696$ [Fig. 5]).

Based on a random-effects model, the cumulative forest plot revealed no significant effect to the effectiveness of light-reflecting devices in reducing AVCs in history (Supplementary data Fig. D). The Kruskal-Wallis test revealed significant differences in the effect size *d*' according to the type of publication ($\chi^2 = 38.1095$, df = 2, $p < 0.001$). The Mann-Whitney *U* test revealed significant differences in the effect size *d*' between articles from other sources such as newspapers and magazines (N = 61, mean = −2.61, SD = 5.61) and reports (N = 118, mean = 0.13, SD = 0.96; [W = 1609, $p < 0.001$]) and no significance differences in the effect size *d*' between reports and scientific publications (N = 6, mean = −0.37, SD = 0.46; [W = 502, $p = 0.26$]) as well as scientific publications and articles from other sources (W = 114, $p = 0.4$). No results could be obtained for "theses" due to fewer data points. However, with focus on nationality the Kruskal-Wallis test revealed significant differences in the effect size *d*' according to the country (Kruskal-Wallis test, $\chi^2 = 57.3778$, df = 5, $p < 0.001$). The Mann-Whitney *U* test revealed significant differences in the effect size *d*' between Canada (N = 88, mean = −0.19, SD = 1.36) and Italy (N = 20, mean = −1.95, SD = 1.81; [W = 1463, $p < 0.001$]), Canada and USA (N = 53, mean = −2.32, SD = 5.91; [W = 837, $p < 0.001$]), Germany (N = 20, mean = 0.06, SD = 0.69) and Italy (W = 334, $p = 0.002$), as well

Table 1
Search results included in the meta-analysis. Bold reference numbers mark references focusing on animal behavior and were excluded from the reanalysis meta-analysis as well as study 18*, 41* and 47* by lack of precise data on AVCs related to the requirements of the meta-analysis. Reference number 8# and 50# are combinations of investigations to behavior and data on AVCs, of which data on AVCs were included in the analysis. Each reference was found either directly or indirectly via reference lists of other authors. We obtained data on AVCs either directly listed in the particular reference or indirectly by contacting the responsible author.

Ref. No.	Author	Title/Source	Person in charge	Search engine	Reference	Data on AVCs	Date of search	Keywords
1	Grenier	A study of the effectiveness of Strieter-Lite wild animal highway warning reflector systems. Commissioned report for Strieter Corporation. 20 p. 2002	–	Google	direct	direct + indirect via Strieter-Lite, The Strieter-Lite Works!	5-Nov-14	wildlife warning reflector australia
2	Schwabe et al.	An analyses of deer-vehicle collisions: the case of Ohio. Hum. Conflicts with Wildl. Econ. Considerations 10, 14. 2000	–	Google	direct	direct	12-Nov-14	wildlife warning reflectors usa
3	Cottrell	Technical assistance report evaluation of deer warning reflectors in Virginia. Technical Assistance Report VTRC 03-TAR6. Virginia Transportation Research Council. 2003	–	Google	direct	direct	10-Nov-14	wildlife warning reflector canada
4	D'Angelo et al.	Evaluation of wildlife warning reflectors for altering white-tailed deer behavior along roadways. Wildl. Soc. Bull. 34, 1175–1183. 2006	–	Google	direct	behavioral study	5-Nov-14	wildlife warning reflectors canada
5	Rogers and Premo	An ecological landscape study of deer-vehicle collisions in Kent County, Michigan. Report for the Michigan State Police, Office of Highway Safety and Planning. White Water Associates, Inc., Amasa, MI 49903. 2004	–	Google	direct	direct	5-Nov-14	wildlife warning reflectors canada
6	Schafer and Penland	Effectiveness of Swareflex reflectors in reducing deer-vehicle accidents. J. Wildl. Manage. 49, 774–776. 1985	–	NA	indirect via Mosler-Berger, C., 2011, Massnahmen gegen Wildunfälle auf Strassen – ein Überblick. Strasse und Verkehr Nr. 6, Juni. p 10–14.	direct	10-Nov-14	–

Table 1 (*Continued*)

Ref. No.	Author	Title/Source	Person in charge	Search engine	Reference	Data on AVCs	Date of search	Keywords
7	Gulen et al.	Evaluation of wild-life reflectors in reducing vehicle-deer collisions on Indiana Interstate I-80/90. Indiana Department of Transportation. Division of Research. Report No. FHWA/IN/JTRP-2006/18. 2006	–	NA	indirect via Huijser, M. et al., 2008, Wildlife vehicle collision reduction study-Report to congress. Report No FHWA-HRT-08-034 2. 251 p.	direct	8-Dec-14	–
8*	Waring et al.	White-tailed deer roadside behavior, wildlife warning reflectors, and highway mortality. Applied Animal Behaviour Science. 29, 215–223. 1991	–	Scholar	direct	direct	6-Nov-14	wildlife warning reflectors canada
9	Reeve and Anderson	Ineffectiveness of Swareflex reflectors at reducing deer-vehicle collisions. Wildl. Soc. Bull. 21, 127–132. 1993	–	Scholar	direct	direct	6-Nov-14	wildlife warning reflectors canada
10	Gladfelter	Effect of wildlife highway warning reflectors on deer-vehicle accidents. Iowa Department of Transportation. Project HR-210. 1984	–	Scholar	direct	direct	10-Nov-14	wildlife warning reflectors usa
11	Sielecki	Wildlife accident monitoring and mitigation in British Columbia, WARS 1988–2007. Special annual report 2010	–	Google	direct	indirect via contact	5-Nov-14	wildlife warning reflectors canada
12	Woodham	Evaluation of Swareflex wildlife warning reflectors. Colorado Department of Highways. Report No. CDOT-DTD-R-91-11. 1991	–	Scholar	direct	indirect via contact	10-Nov-14	wildlife warning reflectors usa
13	Armstrong	An Evaluation of the effectiveness of Swareflex deer reflectors. Ministry of Transportation. Research and Development Branch, MAT-91-12. 1992	–	NA	indirect via Molenaar, J. G. de & Henkens, R. J. H. G., 1998, Effectiviteit van wildspiegels: een literatuurevaluatie. Instituut voor Bos- en Natuuronderzoek Wageningen. IBN-Rapport 362, ISSN: 0928-6888. 103 p.	indirect via contact	16-Dec-14	–

Table 1 (*Continued*)

Ref. No.	Author	Title/Source	Person in charge	Search engine	Reference	Data on AVCs	Date of search	Keywords
14	Zacks	An investigation of Swareflex wildlife warning reflectors. U.S. Department of Transportation Federal Highway Administration. FHWA-MI-RD-85-04. 1985	–	Scholar	direct	indirect via contact; behavioral study	30-Dec-14	wildlife warning reflectors usa
15	Désiré and Recorbet	Protection de la grande faune: expérimentation de réflecteurs en forêt d'olonne, Vendée – Trois années de suivi. 1987	–	NA	indirect via Mosler-Berger, C., 2011, Massnahmen gegen Wildunfälle auf Strassen – ein Überblick. Strasse und Verkehr Nr. 6, Juni. p 10–14.	direct	30-Dec-14	–
16	Ujvári et al.	Effectiveness of wildlife warning reflectors in reducing deer-vehicle collisions: a behavioral study. J. Wildl. Manage. 62, 1094–1099. 1998	–	Scholar	direct	behavioral study	10-Nov-14	wildlife warning reflector usa
17	Nettles	Mirrors to reduce deer-auto collisions. Outdoor Indiana Vlll, 20–23. 1965	–	Google	direct	direct	5-Jan-15	van de ree mirror
18*	Agentschap voor Natuur en Bos	Eindverslag 4 jaar Dood doet Leven, ook in het Zoniënwoud	Raes, D.	Google	direct	direct	5-Jan-15	van de ree wildspiegel
19	ITEK-benelux	Proefproject	van den Berk, M.	Google	direct	direct	5-Jan-15	van de ree wildspiegel
20	Ingebrigtsen and Ludwig	Swareflex wildlife warning reflectors in reducing deer-vehicle collisions in Minnesota. Minnesota Wildlife Reports. Department of Natural Resources. Minnesota Wildlife Report 3. 1986	–	Scholar	direct	indirect via contact	10-Nov-14	wildlife warning reflectors usa
21	Ossinger et al.	Discovery bay deer reflectors. Final research report. Washington State Department of Transportation-Environmental Branch. 1992	–	NA	indirect via Ramp, D. & Croft, D., 2006, Do wildlife warning reflectors elicit aversion in captive macropods? Wildlife Research (33), p 583–590.	indirect via contact	6-Jan-15	–

Table 1 (*Continued*)

Ref. No.	Author	Title/Source	Person in charge	Search engine	Reference	Data on AVCs	Date of search	Keywords
22	Gilbert	Evaluation of deer mirrors for reducing deer-vehicle collisions. U.S. Department of Transportation. Report No. FHWA/RD-82/061. 1982	–	NA	indirect via Zacks, J., 1985, An investigation of Swareflex wildlife warning reflectors. Final report No. FHWA-MI-RD-85-04	indirect via contact	10-Feb-15	–
23	Pepper	Road traffic accidents and deer reflectors. Woodland Ecology Branch. Project Deer population ecology 257. 1998	–	NA	indirect via Langbein et al., 2011, Traffic collisions involving deer and other ungulates in Europe and available measures for mitigation. In: Ungulate Management in Europe: Problems and Practices, eds. Putman, R., Apollonio, M. and Andersen, R. P 215–259.	indirect via contact	10-Feb-15	–
24	Pepper et al.	Deer reflectors and road traffic accidents on roads through Forestry Commission Forests – a review of traffic accident records for roads where deer warning reflectors have been installed. Forest Research, 20p. 1999	–	NA	indirect via Langbein et al., 2011, Traffic collisions involving deer and other ungulates in Europe and available measures for mitigation. In: Ungulate Management in Europe: Problems and Practices, eds. Putman, R., Apollonio, M. and Andersen, R. P 215–259.	indirect via contact	10-Feb-15	–
25	Pafko and Kovach	Experience with deer reflectors. Minnesota Department of Transportation. Office of Environmental Services. 1996	–	NA	indirect via Langbein, J. et al., 2011, Traffic collisions involving deer and other ungulates in Europe and available measures for mitigation. In: Ungulate Management in Europe: Problems and Practices, eds. Putman, R., Apollonio, M. and Andersen, R. P 215–259.	indirect via contact	16-Feb-15	–
26	Ramp and Croft	Do wildlife warning reflectors elicit aversion in captive macropods? Wildl. Res. 33, 583–590. 2006	–	Google	direct	behavioral study	5-Nov-14	wildlife warning reflector australia

Table 1 (*Continued*)

Ref. No.	Author	Title/Source	Person in charge	Search engine	Reference	Data on AVCs	Date of search	Keywords
27	Christensen	Evaluation of Strieter-Lite wild animal highway warning reflector system™ on reducing vehicle-animal collisions. Montana Department of Transportation-Research programs. Project No. HSIP 69-1(22)2. FHWA No. MT 09-02. 2010	–	Google	direct	direct	26-Feb-15	strieter wildlife warning reflector
28	EBA Engineering Consultants Ltd	Animal collision countermeasures on rural Alberta Highways	–	Google	direct	direct	26-Feb-15	strieter wildlife warning reflector
29	BTL Advies BV	Monitoring effecten itek-reflectoren	–	Google	direct	direct	22-Oct-14	wildmolen ongeval
30	Jagdverband Bernau e.V.	Erfolg durch Wildwarnreflektoren	Neigenfind, P.-C.	Google	direct	direct	10-Nov-14	wildwarnreflektor
31	Mindener Tageblatt	Wildwarnreflektoren schrecken Tiere ab. 2013	Westermann, U.	Google	direct	direct	10-Nov-14	wildwarnreflektor
32	Bayerisches Staatsministerium des Innern	Beschluss des Bayerischen Landtags zur Drucksache 16/4155 vom 11.03.2010; betreffend Zulassung von blauen Wildwarnreflektoren. 2010	Mildner	Google	direct	indirect via contact	10-Nov-14	wildwarnreflektor
33	Olbrich	Untersuchung der Wirksamkeit von Wildwarnreflektoren und der Eignung von Wilddurchlaessen. Zeitschrift für Jagdwissenschaft 30, 101–116. 1984	–	Google	direct	direct	10-Nov-14	wildwarnreflektor
34	Wild und Hund	Neub-l-au. Heft 15/2013	Schmitt, P.	Google	direct	direct	10-Nov-14	wildwarnreflektor
35	Die Deutschen Versicherer (GDV)	Unfallhäufungen mit Wildunfällen. Forschungsbericht 01/07. 2007	Voss, H.	Google	direct	direct	10-Nov-14	wildwarnreflektor
36	Viernheimer Nachrichten	Landesstraße 3111: Tempo 60 km/h während der Nachtzeit soll Häufung der Wildunfälle stoppen	–	Google	direct	indirect via contact	11-Nov-14	wildwarnreflektor
37	Hessischer Landtag	Hessischer Landtag-Kleine Anfrage betreffend Elektronik gegen Wildunfälle vom 02.07.2004. 2004	Rhiel, A.	Google	direct	indirect via contact	10-Nov-14	wildwarnreflektor

Table 1 (*Continued*)

Ref. No.	Author	Title/Source	Person in charge	Search engine	Reference	Data on AVCs	Date of search	Keywords
38	Jägerzeitung	Wildwarnreflektoren: gute Ergebnisse. 1/2003	–	Google	direct	indirect via contact	11-Nov-14	wildwarnreflektor österreich
39	Kärntner Jäger	Wildunfälle: Einsatz blauer Wildwarnreflektoren – eine erste Bilanz. Nr. 185/2009	Innerwinkler, K.	Google	direct	direct	11-Nov-14	wildwarnreflektor bericht
40	Österreichischer Verkehrssicherheits-fonds	Wildtierbestände und Verkehr. Reduktion von verkehrsbedingtem Fallwild. Endbericht 2008–2011. 2012	Steiner, W.	Google	direct	indirect via contact	10-Nov-14	wildwarnreflektor
41*	Statens Vägverket	Viltolycksprojektet (VIOL). 1980	Almkvist, B., André, T., Ekblom, S., Rempler, S.-A.	NA	indirect via Olsson, M. & Wid, P., 2007, Vildsvin och Vägar. Slutrapport Kontraktsnummer EK 50 A 2007: 4877. 33 p.	direct	17-Dec-14	–
42	Der OÖ Jäger	Optische Wildwarner im Test. 2011	Moser, E.	Google	direct	indirect via contact	18-Dec-14	dr. ernst moser wildwarner
43	Lück	Untersuchungen an einer Swareflex-Wildwarnreflektoranlage im Reinhardswald. Diploma Thesis. Institut für Wildbiologie und Jagdkunde. Georg-August-Universität Göttingen. 1977	–	NA	indirect via Molenaar, J. G. de & Henkens, R. J. H. G., 1998, Effectiviteit van wildspiegels: een literatuurevaluatie. Instituut voor Bos- en Natuuronderzoek Wageningen. IBN-Rapport 362, ISSN: 0928-6888. 103 p.	direct	22-Oct-14	–
44	NA	Wildwarnerprojekt Oberösterreich	Gösweiner, E.	Google	direct	indirect via contact	22-Dec-14	wildwarnreflektor österreich
45	Rudelstorfer and Schwab	Optische Einrichtungen im Dienste der Verkehrssicherheit. nstitut für Strassenbau und Verkehrsplanung, Universität Innsbruck. Heft 4, 59 p. 1975	–	NA	indirect via Molenaar, J. G. de & Henkens, R. J. H. G., 1998, Effectiviteit van wildspiegels: een literatuurevaluatie. Instituut voor Bos- en Natuuronderzoek Wageningen. IBN-Rapport 362, ISSN: 0928-6888. 103 p.	direct t	17-Dec-14	–
46	Pluntke	Halt bei Blau ist schlau. Bachelor Thesis. Naturwissenschaftliche Fakultät der Gottfried Wilhelm Leibniz Universität Hannover. 2014	–	NA	indirect via email by Mr. Oliver Keuling the advisor of the bachelor thesis	indirect via contact	1-Oct-14	–

Table 1 (*Continued*)

Ref. No.	Author	Title/Source	Person in charge	Search engine	Reference	Data on AVCs	Date of search	Keywords
47*	Liikenneturva – The Central Organization for Traffic Safety	Elk mirrors and traffic. Ministry of Agriculture and Forestry National Board of Public Roads and Waterways Liikenneturva. 1979	Lehtimäki, R.	Google	indirect via Almkvist, B. et al., 1980, Slutrapport Viltolycksprojekt (VIOL). Vägverket TU 146, Borlänge, Sweden. 136 p.	direct	27-Feb-15	–
48	Antonsen and Fjeld	Viltreflektorers innvirkning på elgens kryssing av trafikkert vei. Prosjektoppgave. Høgskolen i Hedmark. 1999.	–	NA	indirect via Storaas T. et al., 2005, Prosjekt Elg – trafikk i Stor-Elvdal 2000–2004 hvordan unngå elgpåkjørsler på vei og jernbane. Høgskolen i Hedmark Oppdragsrapport nr. 1 – 2005. ISBN: 82–7671-440-4. 66 p.	behavioral study	15-Feb-15	–
49	Libjå and Gundersen	Viltreflektorers virkning på elgens kryssing av veg. Prosjektoppgave. Høgskolen i Hedmark. 2001	–	NA	indirect via Storaas T. et al., 2005, Prosjekt Elg – trafikk i Stor-Elvdal 2000–2004 hvordan unngå elgpåkjørsler på vei og jernbane. Høgskolen i Hedmark Oppdragsrapport nr. 1 – 2005. ISBN: 82–7671-440-4. 66 p.	behavioral study	15-Feb-15	–
50#	Lien Aune	Viltreflektorers virkning på elgens kryssing av vei. Bachelor Thesis. Høgskolen i Hedmark. 2004.	–	NA	indirect via Storaas T. et al., 2005, Prosjekt Elg – trafikk i Stor-Elvdal 2000–2004 hvordan unngå elgpåkjørsler på vei og jernbane. Høgskolen i Hedmark Oppdragsrapport nr. 1 – 2005. ISBN: 82–7671-440-4. 66 p.	direct	15-Feb-15	–
51	Checchi	I riflettenti ottici lungo le strade-costi e benefici. Habitat Greentime, 56–58.	–	Google	direct	direct	23-Nov-14	catadiottri antifaunaa
52	Forest research institute of Baden-Württemberg (FVA)	Effektivität von Maßnahmen zur Wildunfallprävention. FVA-einblick, 2/2010, S. 10-11. 2009	Haas, F., Kröschel, M., Strein, M.	Google	direct	indirect via contact	27-Mar-15	wildwarnreflektor baden-württemberg
53	The manitoulin expositor	Jury still out on deer detection systems. 2013	Erskine, M.	Google	direct	indirect via contact	6-Nov-14	wildlife reflector canada

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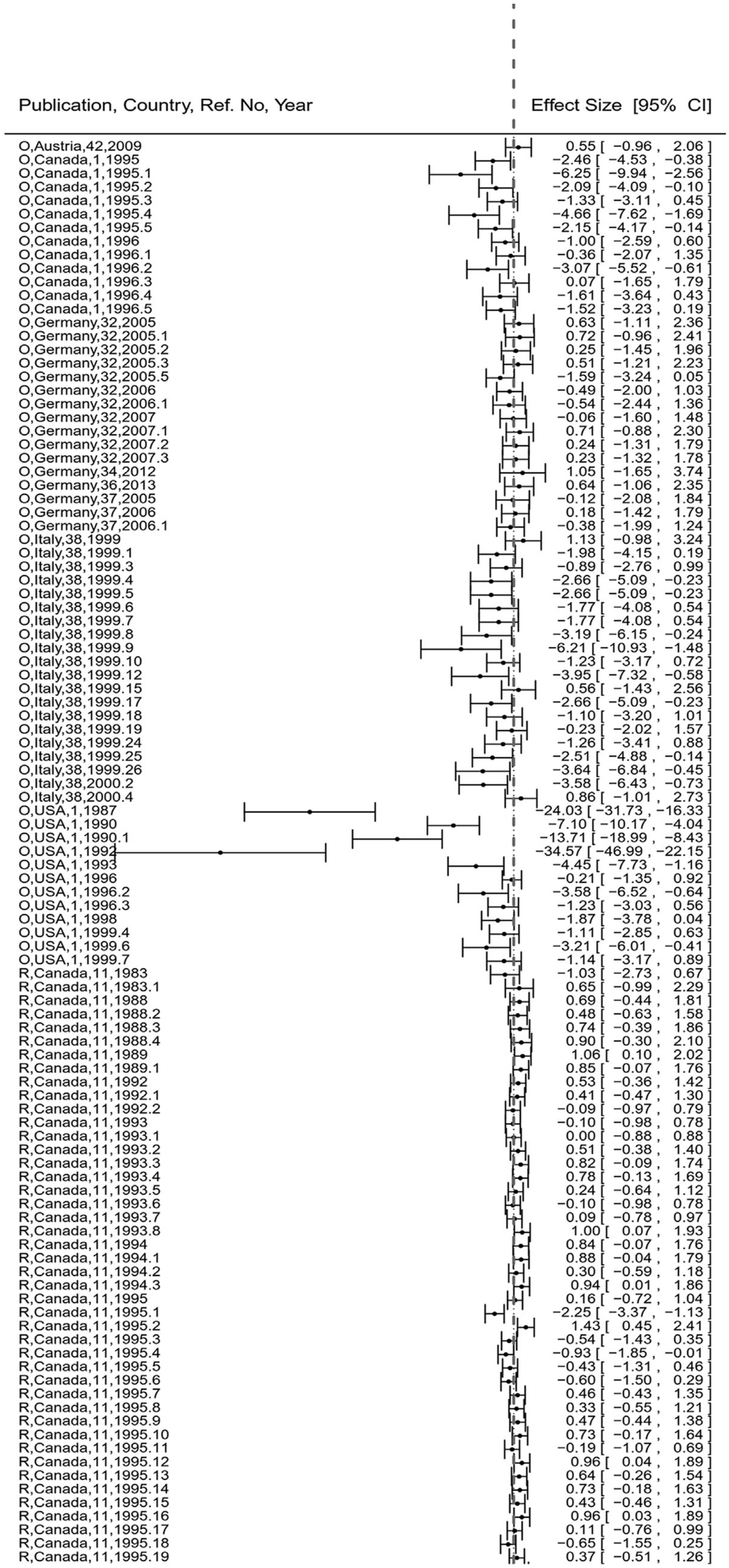

Fig. 2. **A** First part of the forest plot showing the effect size *d*' for each road segment (N = 185) displayed as black dot and the respective 95% CIs as horizontal bars based on random-effects model. Order of data is carried out to: 1) type of publication (O = other type of publication such as articles in newspapers and magazines, R = reports, S = scientific publications), 2) country, 3) reference number (see Table 1) and 4) year of LRD installation. When a reference contained more than one road segment an additional index number is attached. The diamond at the end represents the summarized effect size (-0.50, 95% CI −1.01, 0.01), and the width is proportional to 95% CI. Negative values display a decrease in AVCs after installation of LRDs and vice versa, while the dashed line show an effect size = 0, indicating the absence of an effect of LRDs. **B** Second part of the forest plot.

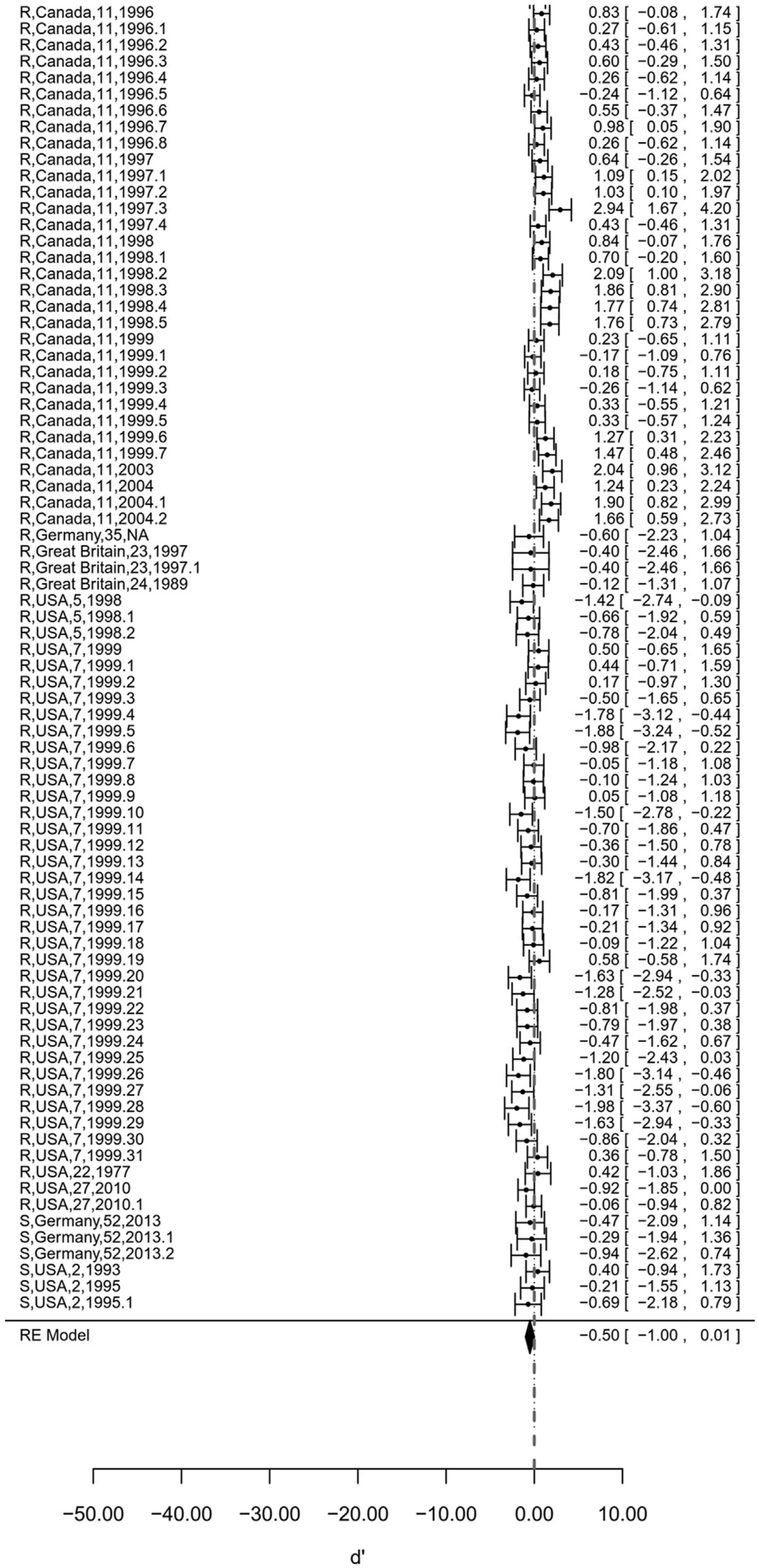

Fig. 2. (*Continued*)

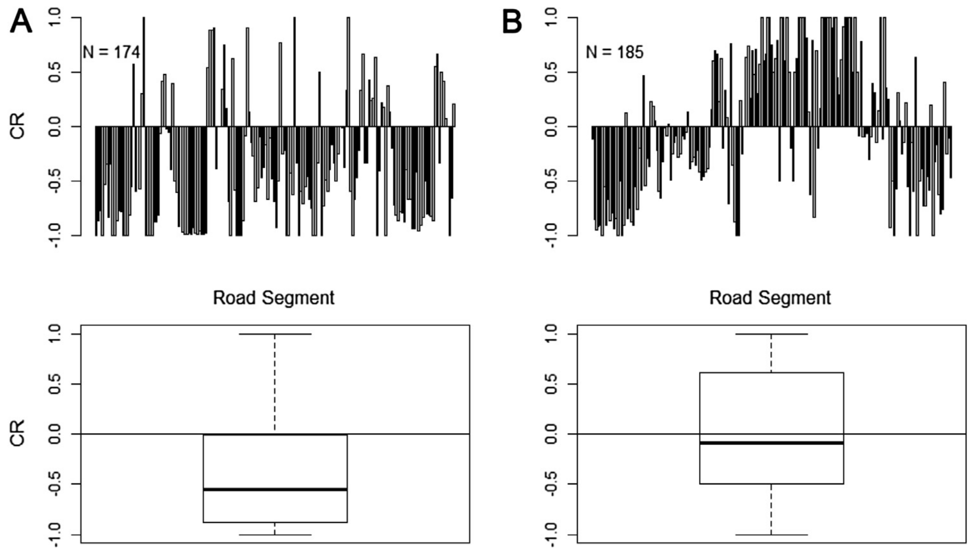

Fig. 3. The collision ratio *CR* per road segment (N = 359) describes the ratio of the difference "number of collisions with light-reflecting device – number of collisions without light-reflecting device" and the maximum number of collisions with and without light-reflecting device (cf. Eq. (4)). Road segments in group A represent the ratio for all road segments with either study duration shorter or equal to two years (short-term studies) or authors have been aggregated annual AVC numbers to a mean AVC value per road segment. Long-term studies in group B contain all road segments with a study duration greater than two years and reported annual AVC numbers. Note that negative values imply a reduction of AVCs after installation of LRDs, while positive values indicate an increase in AVCs. The boxplots illustrate the collision ratio *CR* for all road segments of group A (mean = −0.40, SD = 0.57) and group B (mean = 0.00, SD = 0.64).

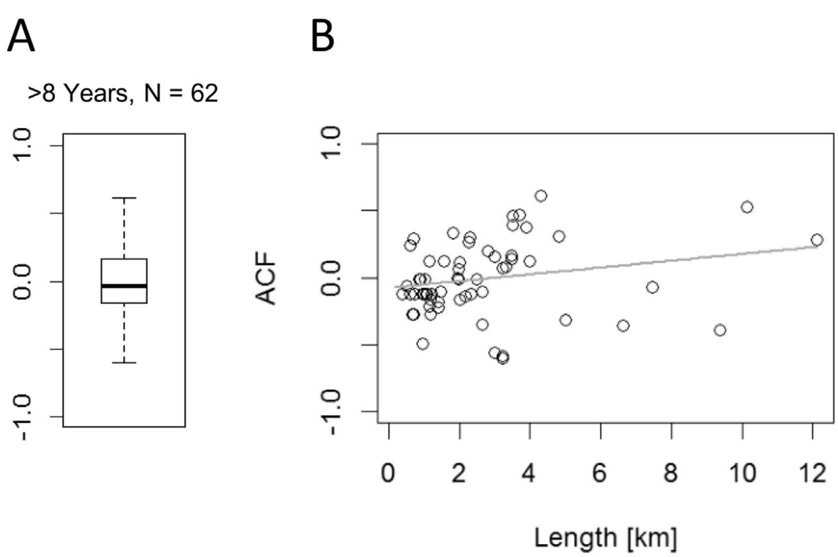

Fig. 4. Temporal autocorrelation in time series of AVC containing eight or more annual collision rates for lag 1 (A). Figure B contains the same ACF-values as shown in A. Gray line reveals linear trend.

as Germany and USA (W = 226, p = 0.001) and no differences in the effect size *d*' between Canada and Germany (W = 1120, p = 0.349) as well as Italy and USA (W = 694, p = 0.259 [cf. Fig. 5]).

The funnel plot uncovered an asymmetric distribution: several road segments with strong negative effect sizes *d*' lay outside the funnel plot, and road segments with positive effect sizes *d*' seem to be missing (Fig. 6) (see Sterne et al., 2011). At the same time, the calculation of the quantity I^2 (Higgins et al., 2003) for 185 road segments with effect size *d*' revealed a value of 55% indicating a moderate to strong heterogeneity among road segments in our meta-analysis (Higgins and Green, 2011; Higgins et al., 2003).

4. Discussion

Extensive research and literature has focused in the last 50 years on testing the effectiveness of LRDs with equivocal findings (e.g. Grenier, 2002; Nettles, 1965; Reeve and Anderson, 1993; Rogers and Premo, 2004; Schafer and Penland, 1985). In this study, we conducted the first meta-analysis on the effectiveness of light-reflecting devices in reducing animal-vehicle collisions. All references have in common that they differed with respect to factors such as study duration, length of road segments, study design, and time of day, which are responsible for equivocal results in the studies until today. For our analysis, we considered three main crucial factors with respect to AVCs: first, study duration and length of road segment, second, study design, and third, time of day when AVCs took place. In addition, we revealed an effect of public attitude towards LRDs that also a human dimension has to be taken into account when focusing on the effectiveness of LRDs.

According to our results the summarized effect size *d*' did not differ significantly from zero, which means that LRDs did not lower

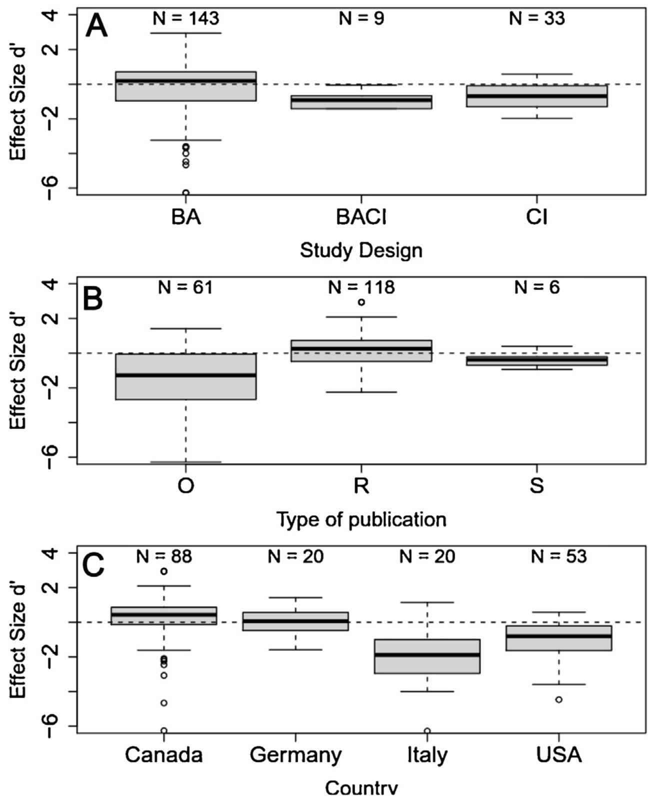

Fig. 5. Boxplots reflecting the effect size *d*' separated for A: study design (BA: Before-After, CI: Control-Impact, BACI: Before-After-Control-Impact), B: type of publication (O: others such as magazines and newspapers; R = reports; S = scientific publications) and C: country (countries with the most extensive data set according to the effect size *d*' [181 of 185 road segments]). Negative values signify reduction of AVCs after installation of LRDs and vice versa. Y-axes are cut for clarify.

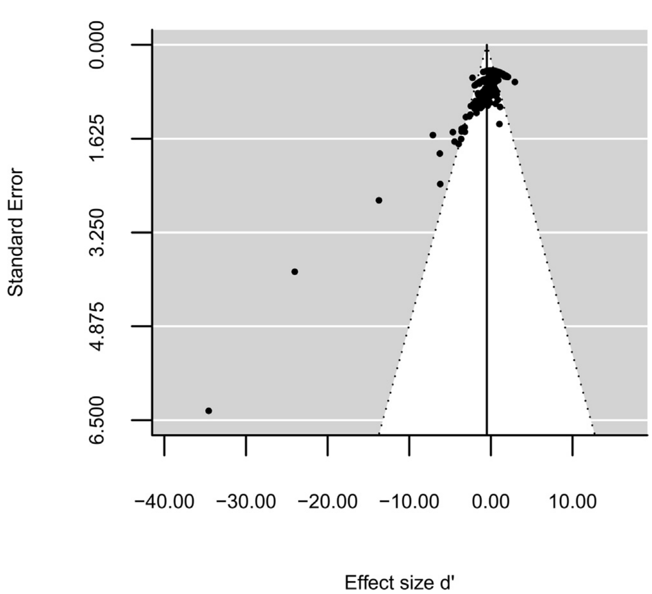

Fig. 6. Funnel plot of the effect estimates from all road segments with effect size *d*' against 1.96 standard error. The vertical line represents the summarized effect size *d*' (−0.50). Without publication bias, most points are expected to fall into the white error cone. Asymmetry clearly shows publication bias.

the number of AVCs, although heterogeneity occurred among road segments (Fig. 2, and I^2 = 55%) and analyzed data contained a publication bias in favor of the effectiveness of LRDs (Fig. 6).

4.1. Inter-annual variation

Results of the temporal autocorrelation function indicated that AVCs were characterized by annual variations, and longer road segments have more carry-over effects on subsequent years than shorter road segments (Fig. 4). A likely explanation is that disparities in AVCs are caused by spatio-temporal patterns of affected species such as variation in population size or shifts in hot spots of AVCs by animal movement. Therefore, we expected a high positive autocorrelation in time series of AVCs for a one-year lag. Our results partly confirmed the results of some authors pointing out that AVCs show high inter-annual variation (Gulen et al., 2006; Rogers and Premo, 2004; Romin and Bissonette, 1996), while others demonstrated that spatial and temporal pattern of AVCs are not random (Langbein et al., 2011; Olson et al., 2015; Steiner et al., 2014). However, inter-annual variation in AVCs is based on natural dynamics such as migration (e.g. Bruinderink and Hazebroek, 1996; Feldhamer et al., 1986; Neumann et al., 2012; Wahlström and Liberg, 1995) and is expected to depend on factors inducing variation in population size in cervids such as cyclic or non-cyclic population fluctuations (Fryxell, 2010), and will likely differ for each species impacted by AVCs. When investigating the effectiveness of LRDs in reducing AVCs spatio-temporal fluctuations in population size and the behavior of affected species has to be taken into account. In our opinion, inter-annual variation in AVCs is one major driving factor for variation in the results in the field of mitigating AVCs.

4.2. Study duration and extent

Short-term studies characterized by study duration less or equal to two years or a mean AVC value per road segment covering more than two years (group A) were more likely than long-term studies that documented annual AVC data (group B) to detect positive effects of light-reflecting devices in reducing AVCs (Fig. 3). While group A attested a decrease of AVCs after installation of devices, there was no reported change found for group B. In addition, we detected a trend (Spearman rank correlation) that the longer the study duration the less efficient LRDs were reported to be in reducing of AVCs.

A likely explanation is that often LRDs are implemented in response to periods of particularly high numbers of AVCs, and their success inferred from AVC levels in the following months or years. However, after peaks in AVC levels (compared to the longer-term mean), AVC numbers are likely to drop again, regardless of whether or not LRDs were installed. Therefore, short-term studies investigating the effect of light-reflecting devices on AVCs will detect more likely a decrease in annual AVC numbers. This hypothesis is strongly supported by results of studies in road accident research, which revealed that comparisons between accident frequencies before and after treatment are an inaccurate approach due to the 'regression-to-mean' effect (Barnett et al., 2005; Hauer, 1986; Wright et al., 1988), an essential topic in road accident research.

In addition, our analysis of the temporal autocorrelation of AVC revealed no autocorrelation for a time lag of one year. The mismatch in temporal scale between study duration and the study system's variability highlights that short-term studies are inappropriate to test temporal changes in AVCs. Investigating the development of AVCs for even shorter periods such as months imply a risk that observed differences in AVCs are owing to seasonal patterns of animal movements (Langbein et al., 2011; Olson et al., 2015; Steiner et al., 2014).

Aside an adequate temporal scale an investigation about the change in number of AVCs should also consider an adequate spatial scale. Investigating the development of AVCs at short road segments imply a risk that hot spots of AVCs shift after installation of

LRDs to locations outside the equipped area, which are neither documented nor investigated. Thus, very localized studies initiated at AVC hotspots are likely to detect a decrease in annual AVC numbers, as animal's road crossing habits shifts. This hypothesis is supported by our finding that AVC numbers will be fewer reduced at longer road segments compared to short ones. The mismatch in spatial scale between length of the road segment studied and the spatial movement pattern of species highlights that short road segments are inappropriate to test temporal changes in AVCs.

4.3. Time of day

We detected no significant difference in the effect size *d*' according to the variable time of day whether AVCs were reduced at twilight or night after the installation of LRDs (daytime vs. nighttime). Just in 14% (6 references with 37 road segments) of all references, AVCs were recorded separately for daytime and nighttime. Instead, 37 references with 328 road segments delivered data on AVCs without distinguishing between daytime and nighttime.

Surprisingly, when implementing studies on LRDs we would expect a precise documentation of daytime vs. nighttime occurrence of AVCs because devices were expected to be effective only during night and twilight (Langbein et al., 2011). At the same time, extensive research and literature describing spatial activity of cervids highlight that behavioral activity is highest at crepuscular and nocturnal time (e.g. Hayes and Krausman, 1993; Klassen and Rea, 2008; Krop-Benesch et al., 2013; Rodríguez-Morales et al., 2013) and pattern of vehicle collisions with cervids are coherent with their activity (e.g. Bruinderink and Hazebroek, 1996; Haikonen and Summala, 2001; Hothorn et al., 2015; Steiner et al., 2014). Nonetheless, in our review, 86% of all road segments did not distinguish between daytime and nighttime.

4.4. Study design

The risk of AVCs itself is affected by external factors such as sight, road characteristics, weather, vegetation, hunting, while the combination of daily traffic and density of road system and animal population density are key factors determining the risk of collisions (Huijser et al., 2007; Langbein et al., 2011; Schwabe et al., 2000; Seiler, 2005). The classic, traditional design used to investigate changes in AVCs is a BA study design. However, only BACI study design take the factors into account that affect AVCs, because impact sites affected by a road (Impact) are compared with non-affected control sites (Control) both before (B) and after (A) some intervention (Roedenbeck, 2007). At the same time, BACI design account for the 'regression-to-mean' effect (Barnett et al., 2005; Hauer, 1986; Wright et al., 1988), thus results are more reliable compared to those of BA design.

In our results, significant differences in the effect size *d*' occurred between BA and BACI study design. While road segments with BA study design attested a weak reported change in the effect size *d*', a trend was detectable that AVC numbers will lower when investigated with BACI study design (Fig. 5). However, BACI design has been conducted only at 9 of 185 road segments, all carried out in the USA, compared to 143 of 185 road segments with a BA design (see Discussion in Fahrig and Rytwinski, 2009). If investigations use a BA study design instead of a BACI design to document changes in the annual number of AVCs per kilometer, which is expected to be neither Gaussian distributed nor characterized by a temporal autocorrelation, a study duration of at least eight years is necessary to obtain robust information about the effectiveness of LRDs to reduce AVCs. However, a study duration longer than eight years bears the risk that systematic environmental changes or cyclic population fluctuations (Fryxell, 2010) affect the annual number of AVCs and thus, the results of studies about LRDs. Therefore, we agree with Roedenbeck (2007) to use the BACI study design for any investigations about changes in AVCs.

4.5. Publication bias and public attitude

According to Romin and Bissonette (1996), reported success of light-reflecting devices in reducing AVCs seems to based on public attitude rather than data. We were interested in how public attitude affects which results are published. Therefore, we included in our literature search not only reports and published papers from scientific journals but also unpublished reports, theses from universities, and articles from magazines, newspapers or manufacturers. Although our literature search contains a bias related to the countries covered and the time of publication, which means that we found more frequently literature in Europe and North America from recent time compared to former decades (Supplementary data Fig. C), we are confident that the countries used for finding relevant data on LRDs were adequate. Actually, most research studying the effects of roads on animal species have been conducted in North America and Europe (Barri, 2010; Puc Sánchez et al., 2013). Data about AVCs and LRDs are rare in other parts of the world (e.g. Delgado, 2007; Barri 2010; Puc Sánchez et al., 2013).

The funnel plot (Fig. 6) clearly revealed a publication bias in our data (Sterne et al., 2011). Further, it indicates that road segments with substantial negative effect sizes ('outliers') might consist of data irregularities: for example when focusing at the road segment with negative effect size *d*' (−24.03) AVC data from treatment period before installation of devices might have been estimated than counted exactly. Moreover, publication bias is caused by missing studies in our meta-analysis, which confirmed no effectiveness of light-reflecting devices in reducing animal-vehicle collisions. Even a publication bias towards the effectiveness of LRDs was detected the summarized effect size *d*' for 185 road segments did not significantly differ from zero.

If public attitude were responsible for publication bias, alterations in history or type of publication should occur. No overall significant effect of devices in reducing AVCs is detectable in past events of LRDs for a time span of almost 40 years (cumulative forest plot; Supplementary data Fig. D). Subsequent, we focused on type of publication how the reported effectiveness of light-reflecting devices in reducing AVCs differed. Road segments based on other type of publications such as articles from magazines, newspapers or manufacturers revealed a significant trend in decreasing AVCs after installation of devices, and scientific publications attested a weak reported change in AVCs after installation of devices. However, reports refuted an effectiveness of LRDs and revealed a tendency that AVCs increase after installation of LRDs. A likely explanation is that the effectiveness of LRDs is dependent on the perspective view. While reports are conducted by administrative institutions (e.g. universities or authorities) that generally pursue non-profit and objective interests, articles within the group of other type of publications are linked with private or economic interests (e.g. private hunters or manufacturers). As a consequence, reports and scientific publications usually provide reproducible and comprehensible results compared to the majority of articles in newspaper and magazines that have anecdotal or narrative character (c.f. Elmeros et al., 2011; Knapp et al., 2004; Lima et al., 2014).

In addition, we revealed in our results remarkable variation in the effect size *d*' with substantial negative outliers within the group of other type of publications compared to reports and scientific publications without such outliers. Consequently, contrary results were detected for countries: while one group reported an effectiveness of devices in reducing AVCs (Italy and USA), a second group reported no effects (Germany) or a slight increase after installation of devices (Canada).

5. Recommendations for future studies

With respect to annual variation in AVCs (Langbein et al., 2011; Olson et al., 2015; Steiner et al., 2014) and high inter-annual variability of AVCs (Gulen et al., 2006; Rogers and Premo, 2004; Romin and Bissonette, 1996), the application of any method applied to prevent AVCs has to be based on reliable investigations using an appropriate study design. We recommend a BACI study design that accounts for population fluctuations in time and space and has the highest inferential strength (Roedenbeck, 2007). Regarding the effectiveness of LRDs in reducing AVCs we recommend investigations which focus on animal behavior instead of comparing collision data. This is essential to understand the behavioral basis of how species respond to LRDs. In our literature review, we found only eight studies investigating animal behavior in the context of LRDs of which six out of eight references showed that devices did not alter animal behavior (Table 1, reference no. 4, 8, 14, 16, 26, and 50).

Future investigations about the potential of light-reflecting devices in reducing AVCs should focus on consistent data collection with mandatory data on i) AVCs strictly separated for daytime and nighttime, ii) length of both study duration of the treatment phases as well as length of the road segment, iii) type and color of devices and date of installation, iv) number of AVCs with information about the species affected.

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Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.aap.2016.08.030.

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