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Do wildlife warning reflectors elicit aversion in captive macropods?

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Abstract. A goal to reduce the frequency of animal–vehicle collisions is motivating extensive research on this topic world-wide. Over the last 30 years, one popular mechanism to warn wildlife of approaching vehicles has been the wildlife warning reflector, manufactured and distributed under the brands Swareflex (Austria) and Strieter-Lite (USA). These reflectors were designed to scare deer and other ungulates from roadways at night by reflecting light from the headlights of approaching vehicles into the eyes of animals on the road verge. Robust documentation of their effectiveness has been lacking, yet there has been a push in Australia to examine their efficacy with regard to medium to large macropodids. Field trials of the reflectors are problematic and difficult to design rigorously, so we chose to examine the behavioural response of two captive macropodid species (*Macropus rufus* and *M. rufogriseus*) to the reflectors on a simulated road in order to derive some indication as to their efficacy. The behavioural response to the reflectors was negligible for both species and not consistent with an aversive effect to deter road use or crossing. We conclude that they would be of little value in our efforts to reduce the frequency of collisions of kangaroos or wallabies with vehicles in Australia.

Introduction

The road network is a significant interface where human activities impinge on the environment. There is growing global concern over the trauma to humans and loss of animal life that result from collisions between animals and vehicles (Sherwood *et al*. 2002; Forman *et al*. 2003). Although the road network is responsible for a variety of other impacts on the environment, and in particular on wildlife populations through habitat fragmentation (Gerlach and Musolf 2000; Goosem 2002; Kramer-Schadt *et al*. 2004) and noise pollution (Reijnen *et al*. 1995; Forman and Alexander 1998), the loss of animal life has serious conservation implications for populations of both common and already threatened species (Lopez 2004; Ramp and Ben-Ami, in press). As a consequence, there is a pressing need to reduce the loss of animal life on roads. Yet collisions with animals on roads also cause significant injuries and fatalities to vehicle occupants, as well as vehicle damage, stimulating efforts to reduce the frequency of collisions solely on human safety grounds (Khattak 2003; Conn *et al*. 2004; Williams and Wells 2005). In order to combat this problem, research has been channelled towards the development of mechanisms that can be implemented to mitigate collision frequency.

One such device developed in the early 1970s by the Austrian company Swareflex® (a company specialising in reflective devices for enhancing road safety) is the wildlife warning reflector, which was designed to prevent collisions with the large ungulates of Europe. The reflectors were modified and marketed in the USA and Canada by Strieter Corporation® in 1994. The reflectors are installed along the road verge in an array that reflects the headlights of oncoming vehicles into the eyes of animals either on the road or on the verge (Fig. 1). The manufacturers contend that this reflected light causes the animals to flee the road before the vehicle arrives. It follows that the reflectors only have the capacity to scare animals off roadways during the night.

Despite being installed in many countries, conjecture surrounds the ability of the reflectors to reduce the frequency of collisions between vehicles and animals. In a commissioned statistical report by Strieter Corporation®, Grenier (2002) found that the reflectors reduced 78 to 90% of collisions where the reflectors were installed correctly across 53 sites in 13 states in the USA and in British Columbia in Canada. In contrast, independent published findings on the effectiveness of this device have at best presented ambiguous results, with most failing to detect any beneficial effect (see Knapp 2004 for a review). The efficacy of the reflectors has been tested in a variety of ways, and these fall into four categories of studies: those that examine fatality rates when reflectors on roads were either covered or uncovered (Schafer and Penland 1985; Reeve and Anderson 1993); those that compare fatality rates before and after the installation of reflectors (Ingebrigtsen and Ludwig 1986; Waring *et al*. 1991); those that compare different road segments with and without reflectors (Gladfelter 1984); and those that investigate the behavioural response of animals either in the wild or in captivity (Waring *et al*. 1991; Ujvari *et al*. 1998). While it is reductions in fatality rates that are goal of any mitigation

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device, studies that have sought to document this have severe limitations and clear responses are difficult to prove (Lintermans 1997). As a result, researchers have sought to quantify the mechanism by which the device works (i.e. behavioural responses to reflected light) in an effort to justify potential effectiveness. These studies have indicated that animals habituate very quickly to the presence of reflectors and that there is no conclusive evidence that they would cause any species of animal to flee (Ujvari *et al*. 1998).

Fatality rates of wildlife in Australia are as high, if not higher, than in the countries where reflectors are currently employed (Ramp *et al*. 2005), and trauma to road users is a growing concern in Australia (Abu-Zidan *et al*. 2002). Australian highways often bisect habitat where native fauna are abundant, and macropodids (kangaroos and wallabies) are often attracted to roadside verges to forage, as the vegetation is often greener and of higher quality than in the surrounding areas (Bennett 1991). Despite the conflicting evidence of their effectiveness, the push to use warning reflectors in Australia for preventing collisions with macropodids has been strong (Lintermans 1997), and some positive results have been found. For example, reflectors reportedly reduced fatalities of the Proserpine rock wallaby in Queensland, although more research was called for (Johnson *et al*. 1993). O'Rourke (1990) found a reduction in hit rates from 12 per month to < 1 per month along a 5-km highway but the study was confounded by a general reduction in fatalities during the study period. Despite these results, the question remains as to whether macropodids react to the reflected light in the aversive way that is suggested to repel ungulates like deer from roads bounded by wildlife warning reflectors.

We therefore examined under controlled captive conditions the behavioural responses of two representative species of macropodids (a large kangaroo *Macropus rufus* and a smaller brush wallaby *M. rufogriseus*) to light from headlights with and without the addition of wildlife warning reflectors. We tested the two most common brands of reflector on the market, Swareflex® and Strieter-Lite®, and used two different colours, red and white. We isolated the response to reflected light from the physical presence of a vehicle and its associated noise by creating an artificial road and simulating the passage of vehicle headlights along it.

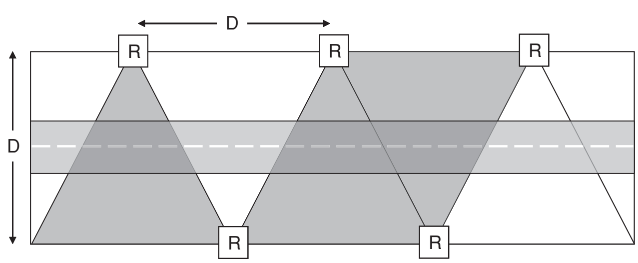

Fig. 1. Typical installation setup of wildlife warning reflectors, adapted from instructions specified by Strieter Corporation®. The positions of the reflectors (R) are staggered on either side of the road at a distance (D) not more than 38 m (for these experiments we used 20 m). The area of effect is indicated by shaded lines.

Methods

Study site and species

The study was conducted at the University of New South Wales Cowan Field Station, ~45 km north of Sydney, Australia, and within Muogamarra Nature Reserve (33°37′35″S, 151°09′20″E). Experimental trials were conducted on *Macropus rufus* (the red kangaroo) and *M. rufogriseus* (the red-necked wallaby). These two species were chosen as they are commonly encountered on roadways in central and eastern Australia, respectively, and are exemplars of the large and medium body-size range of the kangaroos and wallabies. Furthermore, of the native fauna killed on Australian roads, the kangaroos and wallabies are the most similar in size (and eye height) to the ungulates (namely deer) that the reflectors were designed for.

Experimental design

The experiments were conducted in two large and contiguous enclosures (Yard A and B) at Cowan Field Station (Fig. 2). The subjects were twelve male and five female red kangaroos in Yard A, and eight male and seven female red-necked wallabies in Yard B. The yards enclosed a former orchard site which had been cleared of all trees and shrubs and subsequently possessed a relatively uniform cover of tall grasses and herbs (10–50 cm) with some bracken (*Pteridium esculentum*). A 'road' was constructed by mowing to a few centimetres a 10-m wide strip of herbage (mainly grass), traversing both yards. The intention was to attract subjects onto the 'road' as kangaroos and wallabies prefer grazing on short green grasses and herbs (Dawson 1989, 1995). In this way we localised and maximised the observations of behaviour in response to the simulated passage of vehicle headlights. On a real road, the hard surface is unvegetated and macropodids forage on the verge, impacting with a vehicle while crossing or taking flight into its path. Thus our 'road' simulated a broad verge and we encouraged use by regular mowing and localised irrigation by a sprinkler system to stimu-

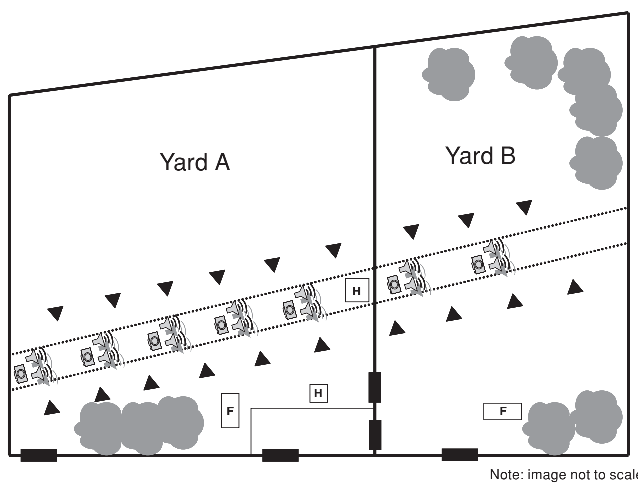

Fig. 2. Depiction of the experimental setup using two yards: (*A*) *Macropus rufus* and (*B*) *M. rufogriseus*. A road strip was mown and sealed-beam headlights installed in pairs every 20 m, along with a CCTV infrared camera. Wildlife warning reflectors were placed on either side of the road and are represented by the black triangles. Hides (H) and supplemental food troughs (F) were also located in the yards, while trees (grey circles) provided shelter.

late and support new growth during the warmer months. In the placement of the 'road' we noted that favoured rest sites were on one side and so we placed supplementary pelleted food and water on the other in order to encourage movement across the road.

Along the road, seven pairs of standard 55-W sealed-beam headlights were installed, ~20 m apart. The lights were fixed to star-pickets at heights of 80 cm and 100 cm apart (average values for sedan cars). The progressive switching on of these lights was controlled by a computer and a daisy-chained pair of addressable A/D switching interfaces (Silicon Chip Magazine, July 1997) with eight relay outputs each. A custom application in Microsoft Visual Basic 6.0 drove the interfaces. The program allowed the parameters of vehicle (headlight) speed (km h^{-1}), vehicle frequency (vehicles h^{-1}) and headlight overlap (dwell time before extinguishing of last switched set with current illuminated headlight set) to be set and the sequence of simulated vehicle passages within an hour to be user-controlled, regular or random. We report the results of trials with 20 random vehicle passes per hour travelling at 60 km h^{-1} over a four hour period each night. We found that owing to the size of the yards, speeds of 100–110 km h^{-1} (typical speed limits of rural roads) required the lights to switch too fast to elicit a measurable response.

An observation hide was built in Yard A, directly in line with the road. The floor of the hide was 2 m above the ground and was supported by a steel base. This hide allowed direct observation of behaviour of kangaroos and wallabies on the road and also housed all computer and video recording equipment. We found that the most effective way to observe and review behaviour was via video recordings. Thus we installed Go-Video Mini-308IR monochrome CCTV cameras with infrared illumination for night viewing on 2-m high star-pickets next to each pair of headlights. The cameras were directed along the road and were spaced so that the entire 'road' was visible at night by the series of cameras. Images from four cameras were combined using a 'quad processor' (images to a 4-way split screen) and recorded on a Panasonic AG-6040 VCR with VHS240 tapes.

Wildlife warning reflectors from the two leading brands, Strieter Corporation (Rock Island, IL, USA) and Swareflex (Wattens, Austria), were used. For both brands, we chose to examine red reflectors given the history of using this colour of reflector world-wide, and also white reflectors to overcome any visual preferences the two species may have for particular wavelengths. The reflectors were installed according to the specifications of the manufacturers (Strieter Corporation 2001, Fig. 1). Strieter Corporation outlines two methods of installation, depending upon whether the area adjacent to the road is flat or on a slope. As the yards used in this study were relatively flat, we used the method stipulated for flat situations. This required the placement of reflectors 20 m apart on either side of the road with a staggered configuration so that reflectors were not directly opposite one another. Reflectors were placed 10 m from the centre of the road so that they were 20 m across from each other and 5 m from the edge of the road. The reflectors have two reflective faces, and these were pointed towards the road so that animals on the road would be illuminated by the reflected light.

The primary objective of this study was to isolate responses to patterns of light. The experimental design was established in such a way as to mimic typical wildlife-vehicle interactions; however the simulation deliberately did not replicate the sound and movement of a vehicle, as in Ujvari *et al*. (1998). Thus we examined the behavioural responses of the macropodids to light, with and without reflectors, presented in a fashion that simulated a moving vehicle. On alternating nights we ran three different simulations. On the first night the lights were kept off for the entire night as a control. For the following night the lights were switched on but the reflectors were covered with black cloth. On the third night the cloth was removed and the lights switched on. This design enabled us to differentiate between the normal behaviour of the subjects, their response to the passage of light and their response to the passage of light in the presence of the reflectors. This 3-day protocol was repeated 15 times consecutively.

Trials were run over a 4-h period beginning at dusk. We used the video recorded from each camera to record the number of subjects that crossed the 'road' (in either direction) during this period. Except for the control night, we recorded the behaviour of subjects that were on the 'road' or at the side of the 'road' during the 'vehicle' simulation. Over the 80 'vehicle' simulations each night, we noted the proportion of subjects that increased their vigilance as a response to the light, comparing the 5 s either side of the simulation. To score vigilance we used the three categories described in Croft (1981). We also noted the proportion of subjects that took flight.

Data analysis

Differences between the proportion of subjects exhibiting vigilance and flight and the number of times subjects crossed the road were compared between treatments for both Strieter-Lite and Swareflex reflectors and both red and white colours. Comparisons were made using the non-parametric tests for paired samples, the Wilcoxon signed rank test and the Friedman test, in SPSS v 13 (SPSS Inc. 2004). Monte Carlo significance estimates (95% confidence levels and 10 000 randomisations) were used to obtain P values. Rather than using a randomised treatment our intention was to measure the response against a shifting baseline to account for any habituation or variation in testing conditions. While the magnitude of response (effect size) was of interest in this study, the main aim was to identify trends in response for the two species, where the addition of reflectors should result in an increase in vigilance and flight and a decrease in crossings (other responses would not be of interest for assisting the reflectors to reduce collisions). As a consequence tests were conducted as one-tailed, rendering P values significant at the 0.05 level when $\alpha = 0.10$ (Quinn and Keough 2002).

Results

Vigilance

A behavioural response to the light was expressed as vigilance ~50% of the time for both species, regardless of the addition of reflectors of either type or colour (Fig. 3). The only significant difference observed at the 0.05 level indicated that vigilance was engaged in more often by *M. rufus* when red Strieter-Lite reflectors were used (Table 1), although the increase in effect was only 13%, from 52 to 65% of the time (Fig. 3).

Flight

Flight in response to light when red Strieter-Lite reflectors were added was significantly higher for *M. rufogriseus* (Table 2), although again this represented an increase of only 5.7%, from 2.8 to 8.5% of the time (Fig. 4). No other significant differences were observed.

Crossing

The number of times each species crossed the road, in either direction, did not differ significantly among treatments for either reflector type or colour (Table 3, Fig. 5).

Discussion

This study represents the first time captive experiments have been conducted to quantify whether wildlife warning reflectors alter the behaviour of macropodids. To do so, it exam-

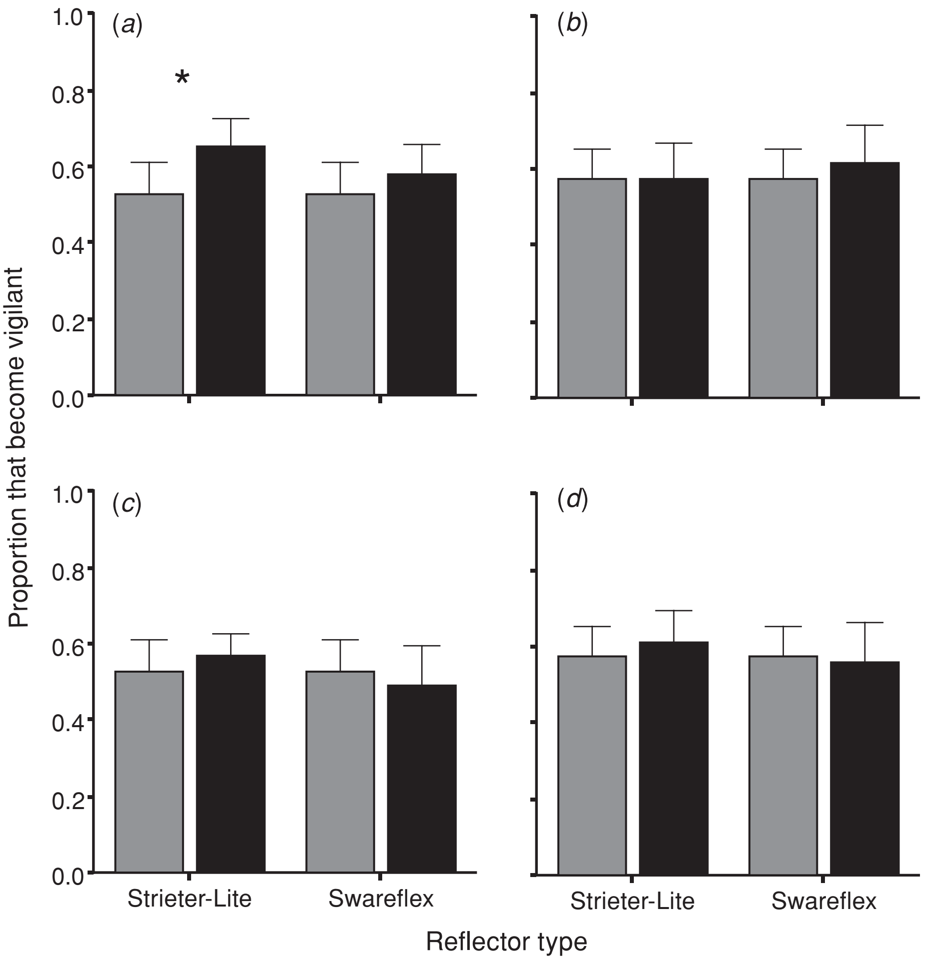

Fig. 3. The proportion of *Macropus rufus* and *M. rufogriseus* becoming vigilant directly after the passage of light along the road, with (black) and without (grey) reflectors. Comparisons represent mean values (±95% confidence intervals) for both Strieter-Lite and Swareflex reflectors and red and white colours. Significance at the 0.05 level (one-tailed) is indicated by an asterisk. (*a*) *M. rufus*, red; (*b*) *M. rufogriseus*, red; (*c*) *M. rufus*, white; (*d*) *M. rufogriseus*, white.

ined how two species of *Macropus* responded to the light emitted from vehicle headlights, isolated from the additional effects of sound and motion. We observed that given a light source simulating the traverse of a car along a road, ~50% of both *M. rufus* and *M. rufogriseus* exhibited an increased vigilance response. This effect represents a 'freeze' response, and kangaroos are often reported to stand erect yet remain motionless when approached by vehicles at night (E. Lee, unpublished data). The proportion of subjects that fled in this situation was 5% or less for both species.

Quantitative analysis of vigilance and flight responses to oncoming vehicles under real circumstances are so far lacking. However, in one unpublished study of three kangaroo species responses to approaching vehicles along the Silver City Highway in far-west New South Wales Australia, considerable variation in the proportion of kangaroos exhibiting

Table 1. Vigilance response to reflectors

Comparison of the proportion of *Macropus rufus* and *M. rufogriseus* becoming vigilant directly after the running of the light system with and without reflectors. Wilcoxon signed rank tests with 10 000 Monte-Carlo permutations were used to derive *P*-values, reported for both one- and two-tailed tests. $N = 15$

Species	Type	Colour	z	$P_{(\text{two-tailed})}$	$P_{(\text{one-tailed})}$
Macropus rufus	Strieter-Lite	Red	–1.960	0.055	0.027
		White	–0.824	0.430	0.213
	Swareflex	Red	–1.258	0.217	0.107
		White	–0.852	0.412	0.207
Macropus rufogriseus	Strieter-Lite	Red	0.000	1.000	0.510
		White	–0.683	0.504	0.252
	Swareflex	Red	–1.109	0.278	0.143
		White	–0.454	0.679	0.333

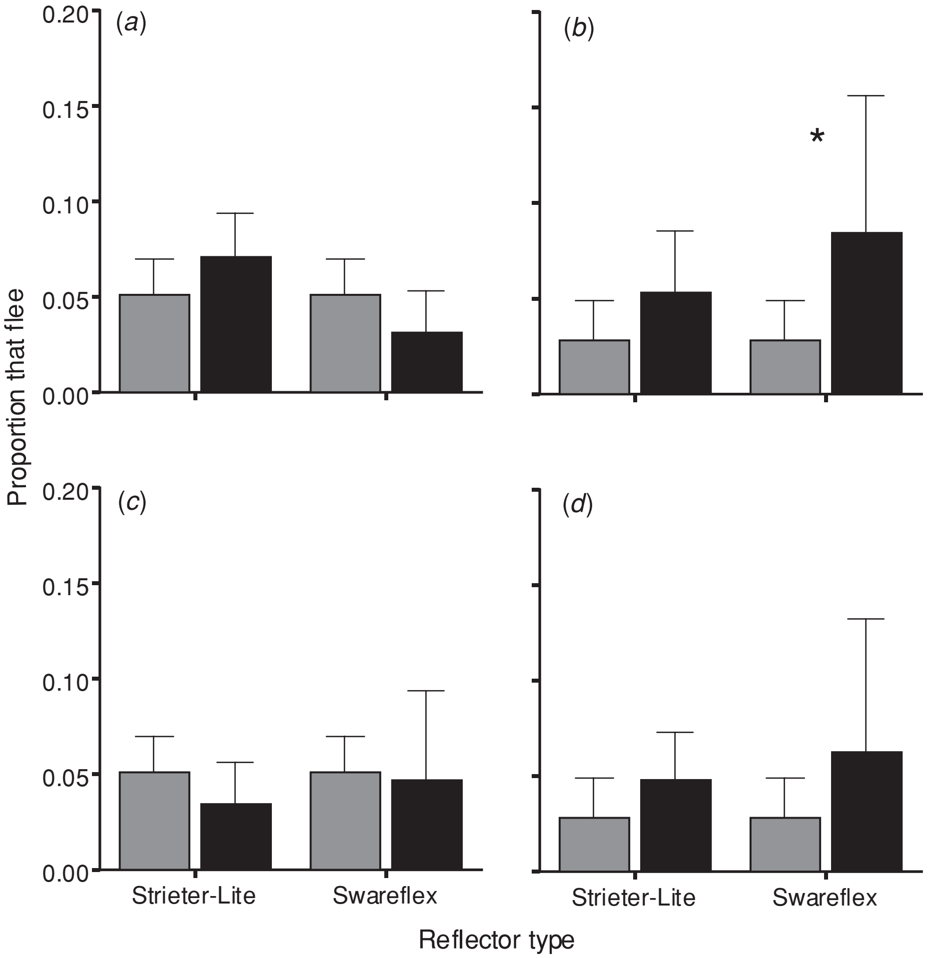

Fig. 4. Proportion of *Macropus rufus* and *M. rufogriseus* fleeing the road directly after the passage of light, with (black) and without (grey) reflectors. Comparisons represent mean values (±95% confidence intervals) for both Strieter-Lite and Swareflex reflectors and red and white colours. Significance at the 0.05 level (one-tailed) is indicated by an asterisk. (*a*) *M. rufus*, red; (*b*) *M. rufogriseus*, red; (*c*) *M. rufus*, white; (*d*) *M. rufogriseus*, white.

either vigilance or flight responses was observed (E. Lee, unpublished data). During the night, kangaroos were more likely to exhibit flight (68%) as opposed to vigilance (23%), while during the day kangaroos were most likely to exhibit vigilance (51%) than flight (31%). This indicates that the response adopted by an individual may depend upon whether they can obtain a visual fix on the approaching vehicle. While the vigilance responses obtained in this study with captive animals were similar in range to those observed along the Silver City Highway, the flight responses were proportionally less frequent. This suggests that under captivity, kangaroos and wallabies may be less likely to flee as captivity is well known to dampen behavioural responses through effects like habituation and the physical constraints of small enclosures.

The addition of either Strieter-Lite or Swareflex warning reflectors, in either red or white, had either no effect or only

Table 2. Flight response to reflectors

Comparison of the proportion of *Macropus rufus* and *M. rufogriseus* fleeing the road directly after the running of the light system with and without reflectors. Wilcoxon signed rank tests with 10 000 Monte-Carlo permutations were used to derive *P*-values, reported for both one- and two-tailed tests. $N = 15$

Species	Type	Colour	z	$P_{(\text{two-tailed})}$	$P_{(\text{one-tailed})}$
Macropus rufus	Strieter-Lite	Red	–1.156	0.274	0.135
		White	–0.884	0.436	0.227
	Swareflex	Red	–1.593	0.123	0.063
		White	–1.425	0.157	0.081
Macropus rufogriseus	Strieter-Lite	Red	–1.966	0.045	0.021
		White	–1.340	0.188	0.091
	Swareflex	Red	–1.296	0.217	0.105
		White	–1.041	0.313	0.155

Table 3. Crossing in response to reflectors

Comparison of the number of *Macropus rufus* and *M. rufogriseus* crossing the road under control conditions, with light, and with light plus reflectors. Friedman tests with 10 000 Monte-Carlo permutations were used to derive *P*-values. $N = 15$

Species	Type	Colour	χ^2	$P_{(two\text{-}tailed)}$
Macropus rufus	Strieter-Lite	Red	2.533	0.331
		White	0.933	0.708
	Swareflex	Red	1.458	0.496
		White	2.370	0.307
Macropus rufogriseus	Strieter-Lite	Red	0.533	0.791
		White	1.254	0.576
	Swareflex	Red	1.254	0.580
		White	0.255	0.910

a small significant effect on the behaviour of both *M. rufus* and *M. rufogriseus*. With red Strieter-Lite reflectors in place a small increase in the vigilance of *M. rufus* was recorded, and *M. rufogriseus* showed a small increase in the flight response. While some alerting or aversive effect is encouraging, the small size of such behavioural responses by just one type of reflectors, albeit in captivity, limits their utility in substantially mitigating animal–vehicle collisions. The response or lack thereof may be species-specific but there is no evidence that the species tested are unrepresentative of the Macropodidae in terms of reactivity to threatening stimuli (Jarman and Coulson 1989).

The ability of wildlife warning reflectors to elicit a response in macropodids relies on the extent of the visual field of the subjects in question. Most marsupials have dichromatic vision although there is currently a paucity of data (Deeb *et al*. 2003). One recent study has suggested that some marsupials may possess trichromatic colour vision

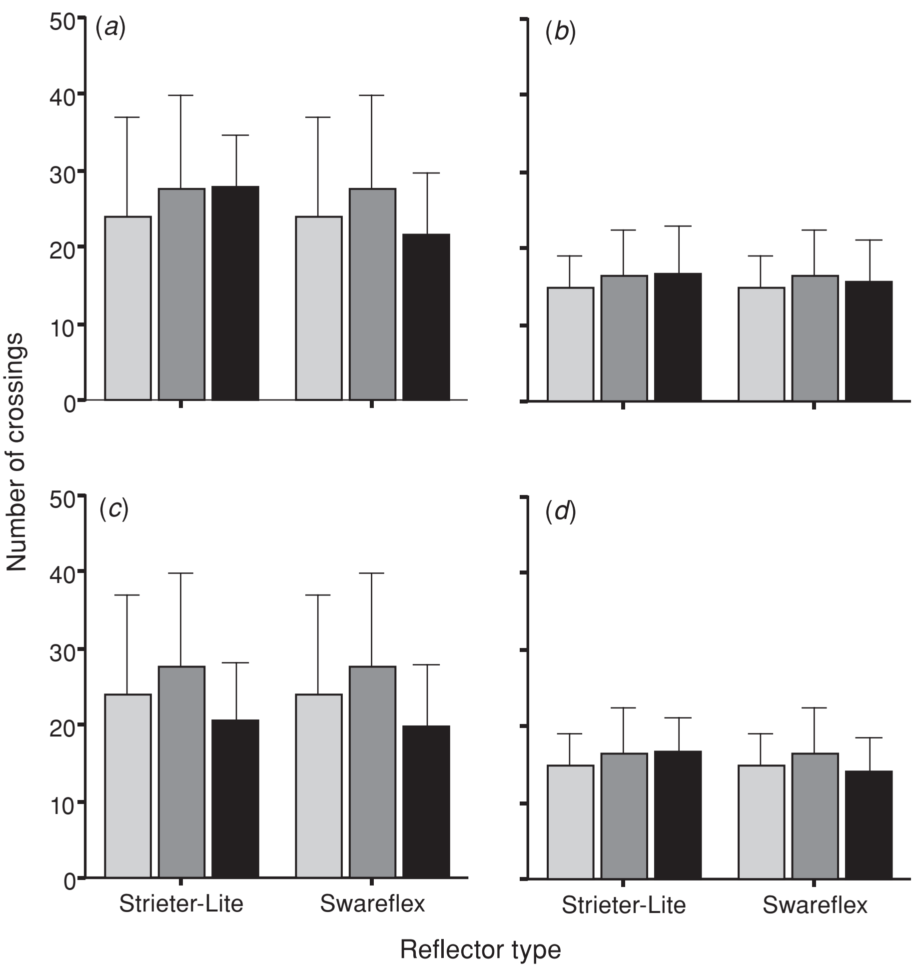

Fig. 5. Number of *Macropus rufus* and *M. rufogriseus* crossing the road, with (black) and without (dark grey) reflectors. Comparisons represent mean values (±95% confidence intervals) for both Strieter-Lite and Swareflex reflectors and red and white colours. Significance at the 0.05 level is indicated by an asterisk. (*a*) *M. rufus*, red; (*b*) *M. rufogriseus*, red; (*c*) *M. rufus*, white; (*d*) *M. rufogriseus*, white. Controls are indicated by light-grey bars.

(Arrese *et al*. 2002), yet attempts to prove this in the wallabies and kangaroos have so far proven unrewarding (Hemmi *et al*. 2000; Deeb *et al*. 2003). To date, the standard reflectors used in the USA, Canada and in Europe for ungulates have been red. Research on the colour spectrum visible to deer, however, has suggested that maximum absorbance by deer is closer to 500 nm, rather than the 650–700 nm wavelengths produced by red light (Jacobs *et al*. 1994). Similar vision patterns have been observed in the tammar wallaby (*M. eugenii*), with a peak absorbance at 501 nm and another peak at 539 nm (Hemmi *et al*. 2000). Based on current information, it is likely that the recommendation to switch from using red reflectors to other colours for ungulates, such as white, green and amber (Sielecki 2004), would also hold true for Australian marsupials. Nonetheless, we gained a greater response from red, rather than white, reflectors.

A complete spectrometric evaluation of the reflective properties of the reflectors was conducted by the British Columbia Ministry of Transportation and Highways (Sivic and Sielecki 2001). Testing both Strieter-Lite and Swareflex reflectors, the study found that under laboratory conditions the illuminance of the reflectors with a standard vehicle headlight was less than 0.1 lx at a distance of 2 m from the source, regardless of colour (cf. on a clear night, full moon illumination level is 0.1 lx). The minimal additional illumination contributed by the reflectors compared to the overwhelming stimulus of rapidly approaching bright headlights may explain why we generally failed to get a significant addition to the baseline behavioural response to headlights alone. However, given the high sensitivity of nocturnal eyes further research on the optimal illumination to cause alertness and measured withdrawal from the road as compared to temporary blindness, inertia and confused flight is warranted. From anecdotal evidence, some drivers believe that dimming or switching off headlights helps avoid collisions with kangaroos.

The statistical power of many of the previous roadside trials conducted in Australia has been questioned (Lintermans 1997), making them likely to fail because of insufficient replicates and poor sampling design. To counteract this, we have conducted a rigorous captive study to avoid many of the pitfalls of field trials. In doing so, we have failed to detect a sufficient response from our two chosen species to warrant recommendation of appropriately designed field trials. We recognise that our captive trials do not fully reflect all of the variables that might contribute to a beneficial response to reflectors. In particular, the removal of the vehicle was a necessary component of our study to target the role of light in eliciting flight behaviour, yet the physical presence of a vehicle with light may be important. Possible questions raised by this study are therefore how the reflection of low intensity light might combine with the presence of an approaching vehicle to amplify the behavioural response, and if so, what impact would habituation have on the behavioural response if permanently installed at a location, as habituation has already been shown to dampen any initial behavioural response to reflectors (Ujvari *et al*. 2004). The issue is whether reflected light evokes a sufficient alerting or evading behavioural response in medium to large Australian fauna that would result in fewer collisions with vehicles. We failed to record such a response and so installation of wildlife warning reflectors on highways at hotspot locations must be treated as a dubious solution to the problem of wildlife-vehicle collisions in Australia. While the need to improve human safety and conserve wildlife populations is paramount, solutions to this problem are most likely going to require radical rethinking of road and vehicle design, as well as a changing of attitudes in drivers, rather than from deterrents aimed at causing animals to flee roads.

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