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Visual deception of a male *Libellula depressa* by the shiny surface of a parked car (Odonata: Libellulidae)

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Abstract

A male *Libellula depressa* was observed to mistake a dark-green passenger coach for a water body thus establishing his territory over the surface of the vehicle and using the radio antenna as perch. A videopolarimetric analysis of the car body showed that the light reflected from the bonnet was highly and horizontally polarized with rather similar polarizational characteristics in the red, green and blue part of the spectrum. It is concluded that the insect was deceived by the reflected horizontally polarized light resembling the corresponding pattern at a plane water surface.

Introduction

Sunlit car bodies have repeatedly been reported to attract sexually active odonates. In most cases females of libellulid species were involved that oviposited on the horizontal surfaces of the vehicles (e.g. Svihla 1961; Watson 1982; Günther 2003), sometimes causing serious damage to the clearcoat of the car body (Stevani et al. 2000a, 2000b). In contrast, males are rarely seen to stay over parked vehicles. The only such account refers to several individuals of *Crocothemis erythraea* (Brullé) that showed territorial behaviour over car roofs (Torralba Burrial & Ocharan 2003). Both sexes are obviously deceived by the light reflected from the car surface that is mistaken for a water body. Choice experiments with surrogate materials such as perspex plates, plastic sheets and aluminium foils revealed that it is most probably the horizontal polarization of the reflected light that leads odonates to confuse plane artificial surfaces with water (Wildermuth 1998). Some species find oil surfaces visually even more attractive than water because the degree of linear polarization of oil-reflected light is higher than that of water-reflected light (Horváth et al. 1998); thus puddles of waste and crude oil may be fatal traps for many water insects (Horváth & Zeil 1996; Bernáth et al. 2001). The polarizational features of natural and artificial surfaces can be analysed by videopolarimetry, for example, that yields quantitative information on the intensity, degree and angle of the linear polarization of the reflected light in various parts of the spectrum

(Horváth & Varjú 1997, 2003). Among libellulids *Libellula depressa* Linnaeus has been shown in both sexes to mistake glass panels, perspex and plastic sheets for water (Wyniger 1955; Wildermuth 1998). Here we describe an observation of a male *L. depressa* that established his territory over a car (Fig. 1) and present the results of a videopolarimetric analysis of the corresponding car surface.

Materials and methods

The incidental observation was made near Puyméras in southern France (44°17'N, 05°08'E), on 8 June 2004 from 12:35 to 13:00 h solar time on a very warm, cloudless day. The car (type: Honda Civic, shiny dark green) over which two males displayed territorial behaviour was parked in an almost horizontal position in full sunshine between the concrete wall of a house-garden and a vineyard, at least 1 km away from the nearest water body suitable as a breeding place for the species. The event was witnessed by two persons and photographically documented.

The reflection-polarization patterns of the car (Figs 2-4) were measured on 25 June 1999 in Rüti, Switzerland (47°16'N, 08°52'E) at 09:30 h solar time on a sunny day, under a clear sky, by videopolarimetry in the red (R), green (G) and blue (B) part of the spectrum at $\lambda_B = 450 \pm 40$ nm (wavelength of maximal sensitivity ± half bandwidth of the camera's CCD sensors), $\lambda_G = 550 \pm 40$ nm and $\lambda_R = 650 \pm 40$ nm. The viewing angle of the videopolarimeter was horizontal. The method of videopolarimetry is described in detail by Horváth & Varjú (1997).

Figure 1: Territorial male of *Libellula depressa* perched on the tip of the radio antenna of a dark-green car parked by a vineyard. The body axis is held parallel to the steeply incident sun rays, thus minimising heating of the body. The real colour of the car roof is not visible because the sky and the nearby surroundings are mirrored at the shiny surface.

Results

Observation

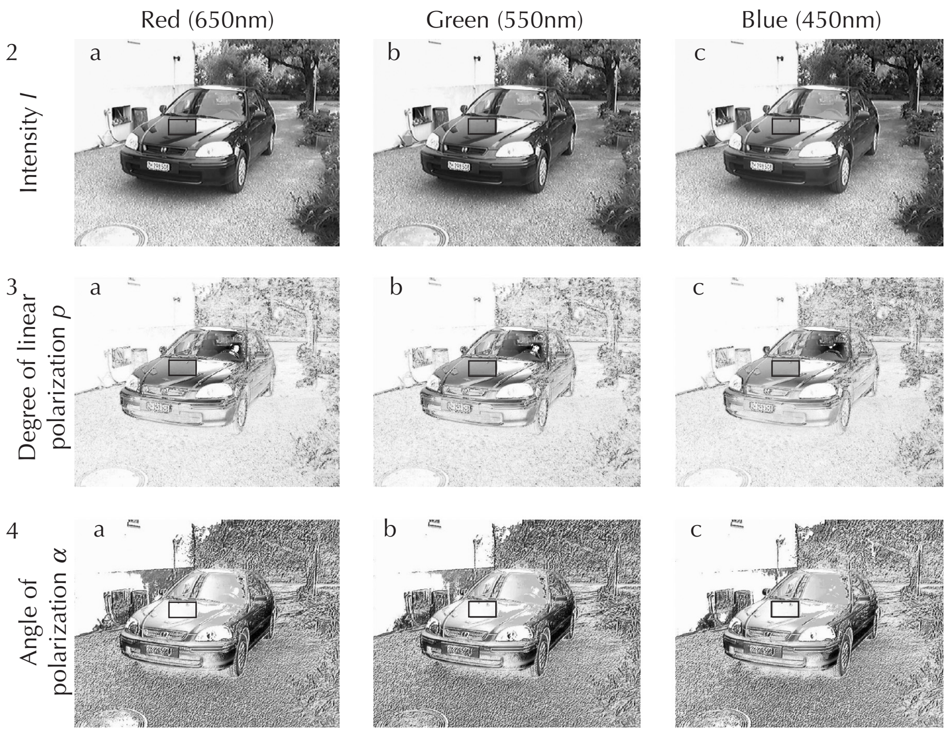
The male *Libellula depressa* was detected while it was already circling over the parked car. It patrolled above the bonnet and the roof, flying in loops and circles between ca 0.1 to 1.0 m above the shiny surface. The insect kept close to the vehicle and returned immediately after making excursions into the nearby surroundings. During at least 2 min it neither touched the car surface nor perched on or near it. When a second male approached the resident darted towards it and the contestants spiralled up to 10 m high and more than 20 m away from the vehicle. For a moment both insects were out of sight. After the fight that lasted ca 15 s one of the males – perhaps the territory holder – returned to the car and continued patrolling. Shortly afterwards he unsuccessfully tried to perch on the metal part of the 50 cm long obliquely extended radio antenna. The latter was unacceptable, perhaps being too hot, and the male repeatedly withdrew as soon as he touched the metal surface with his legs. Finally he perched on the plastic knob at the end of the antenna that was less hot than the metal although its colour was black. The insect positioned its body axis parallel to the steeply incident sun rays with the head directed to the sky, thus minimising heating of the body (Fig. 1). As at natural habitats, the territory holder started to make patrol flights from time to time from his perch and returned to it after some loops over the bonnet and roof of the vehicle. After 15 min, i.e. when the extensive photographic documentation was finished and no new behavioural elements could be observed, the antenna was pushed back and the perch was replaced by a wooden stick fixed at the upper end of the right front door. The dragonfly returned immediately after this manipulation and accepted the new perch without hesitation. Ten min later the vehicle was moved backwards at low speed (2-3 km/h). The male followed the car, staying mostly over the roof for ca 30 m, and then left the site definitely.

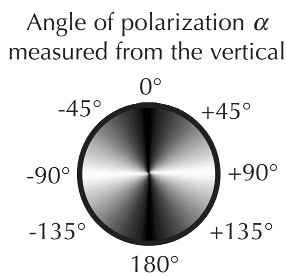
Polarisation pattern of the car surface

Figures 2-4 show the reflection-polarizational characteristics of the car over which *L. depressa* was observed. Figure 5 displays the frequencies of the degree of linear polarization p and Figure 6 the angle of polarization α of light reflected from the bonnet in the red (650 nm), green (550 nm) and blue (450 nm) parts of the spectrum. Because the paint of the car was very dark green, the intensity I, degree of linear polarization p and angle of polarization α of light reflected from the car body depended only slightly on the wavelength. It is obvious from Figures 3a-c that the car body reflected highly polarized light, especially the bonnet and the wind screen. The light reflected from the bonnet was horizontally polarized (Figs 4a-c, 6a-c), while the car doors reflected vertically polarized light. The mean of p of light reflected from the bonnet was p_{mean} = 37.1%, 34.6% and 29.5% in the red, green and blue parts of the spectrum, respectively.

Discussion

The male *Libellula depressa* exhibited exactly the same territorial behavioural elements such as patrolling, perching, chasing rivals over the car as the species normally shows at reproductive sites. It typically inhabits small stagnant water bodies at the pioneer stage, i.e. when they are not or only sparsely overgrown. In urbanized and agriculturally intensively used regions like in most European countries the reproductive habitats are puddles and ponds in gravel and clay pits or freshly established water bodies in gardens or nature reserves (Sternberg 2000; Schmidt 2001).





Figures 2-4: Reflection-polarizational characteristics of the car that a male *Libellula depressa* mistook for a reproduction site. (2) The patterns of intensity *I*, (3) degree of linear polarization *p* and (4) angle of polarization *α* (measured clockwise from the vertical) of light reflected from the car body were measured by videopolarimetry in the (a) red (650 nm), (b) green (550 nm) and (c) blue (450 nm) parts of the spectrum. The small rectangle on the bonnet shows the region for which the frequencies of *p* and *α* of reflected light were calculated and are shown in Figures 5, 6.

In contrast to these secondary habitats, the primary habitats probably lay in the floodplains of natural rivers, consisting of small lentic water bodies that disappeared during occasional floods and were simultaneously created freshly at new sites. Therefore it may be presumed that both sexes of *L. depressa* are adapted to the dynamics of river systems and steadily disperse in search of new breeding localities. These behavioural traits may explain why the males discovered the car remote from any suitable breeding site. Furthermore, car bodies resemble water bodies in the pioneer stage because they generally lack structures that interrupt the homogeneous plane. However, most importantly for the attraction of *L. depressa*, is the polarization of light reflected from the surface of the car body. By choice experiments with shiny plastic sheets and perspex plates of different colours it was shown that they attract both sexes of this species, the males establishing territories and mating, and the females ovipositing at the surrogates (Wildermuth 1998, and unpubl.). The sheets reflect highly and horizontally polarized light. Females were also seen to lay eggs on glass panels (Wyniger 1955) that also act as polarizers. This is in contrast to aluminium foil that, although it strongly reflects the partially linearly polarized skylight, does not polarize it horizontally and hence is not attractive for both sexes searching for breeding localities (Horváth et al. 1998; Wildermuth 1998).

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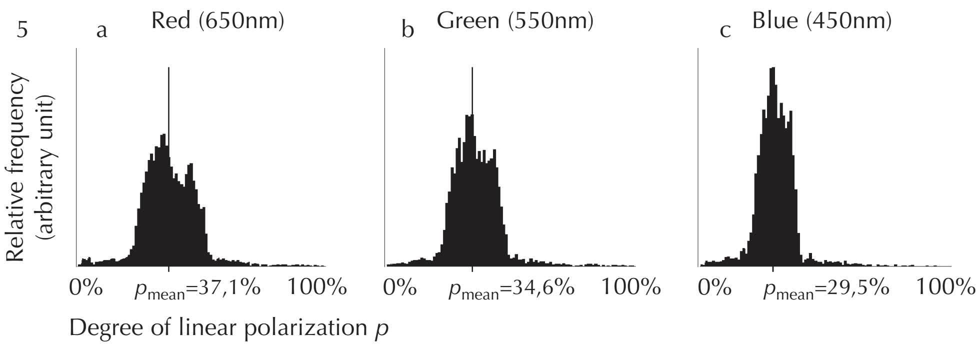

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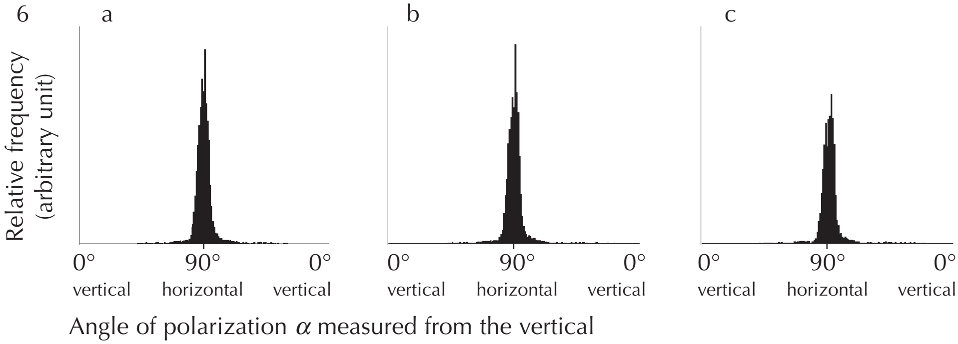

Figures 5,6: Relative frequencies of (5) the degree of linear polarization p and (6) the angle of polarization α (measured clockwise from the vertical) of light reflected from the rectangular region of the car in Figures 2-4 calculated for the red (650 nm), green (550 nm) and blue (450 nm) parts of the spectrum. In Figure 5 the p_{mean} is displayed by a vertical line.

The shiny bodywork of cars usually reflects such highly polarized light (Figs 2-4) that it can attract water-seeking polarotactic insects with a polarization-sensitive visual system. Many aquatic insects recognize their natural habitat on the basis of the highly and horizontally polarized light reflected from the water surface (Schwind 1991, 1995). Odonates too find the water by polarotaxis (Horváth et al. 1998; Wildermuth 1998). There are accounts of a variety of insects associated with water, including anisopterans that were deceived by shiny car bodies (Fernando 1958; Svihla 1961; Popham 1964; Watson 1992; Günther 2003; Torralba Burrial & Ocharan 2003). A. Torralba Burrial (pers. comm.) recently observed dozens of male *Crocothemis erythraea* that established their territories over car bodies on a large car park in northeastern Spain. The attactiveness of planes covered with paint and clearcoat for odonates may be explained by the fact that their polarizing abilities resemble those of stagnant waters (Horváth & Varjù 1997). As the surface of sunlit cars can heat up to more than 90°C (Stevani et al. 2000b) severe problems arise for those individuals that try to perch over the car or to touch the surface with the abdominal tip while ovipositing. Difficulties may also arise for the car industry because eggs laid onto vehicles can damage the resin of the coach work as does acid rain. Stevani et al. (2000a, 2000b) showed that the eggs of *Miathyria* sp., *Tauriphila* sp., and *Erythemis* sp. at temperatures between 50 and 92°C produce sulfinic and sulfonic acids that destroy the clearcoat.

From Figures 3-6 it is evident that the more or less horizontal parts of the bodywork reflect highly and horizontally polarized light and this explains why polarotactic dragonflies are deceived by and attracted to cars: the bodywork mimics a water surface according to the insects' visual system. Beyond polarization, the colour of the paintwork may also influence the odonates' behaviour. Yet the role of colours for the attractiveness of car bodies to anisopterans is still to be investigated. As the polarizational characteristics of bright and dark water bodies differ, it is assumed that odonates can distinguish them (Bernáth et al. 2002). However, for *L. depressa* the brightness may be irrelevant as a cue, for, according to our observations in Central Europe, this species is attracted by almost whitish clay puddles as well as nearly black peat diggings.

The angle of view strongly influences the reflection-polarizational characteristics of car bodies. Generally the direction of polarization of light reflected from a non-metallic (dielectric) bodywork follows the curvature of its surface, because the reflected light becomes partially linearly polarized parallel to any dielectric reflector in such a way that the plane of oscillation is perpendicular to the plane of reflection determined by the incident and reflected rays and the normal vector of the surface at the point of reflection. The degree of linear polarization of reflected light depends on the angle of reflection: at smooth surfaces there is a characteristic angle of reflection – the Brewster angle, ca 57° to the horizontal plane – at which the reflected light is maximally polarized. Thus, changing the direction of view, the plane of reflection also changes with respect to the local normal vector of the observed surface, the consequence of which is to change both the degree and angle of polarization.

The surface roughness as well as the colour of the bodywork also strongly influences the reflection-polarizational characteristics of a car. Since rough surfaces reflect light diffusely, which reduces polarization, the rougher the bodywork the lower the degree of linear polarization of reflected light. The darker a bodywork in a given spectral range, the higher the degree of linear polarization of reflected light. The reason for this is as follows: the surface of the transparent clearcoat of the car body reflects more or less partially linearly polarized light depending on the incident angle, but almost independently of the wavelength, and the direction of polarization of this reflected light is parallel to the surface. The colour of the bodywork arises from the selective absorption and diffuse scattering of light in the paint layer below the transparent clearcoat. The diffuse light emanating from this paint layer is originally unpolarized, but it becomes partially linearly polarized after transmission and refraction at the surface of the clearcoat. The direction of polarization of the paint-scattered light is perpendicular to the clearcoat surface because of refraction polarization. Hence, the net degree and direction of polarization of a car surface are determined by the superposition of the clearcoat-reflected and the subclearcoat-scattered (i.e. paint-scattered) light. If the former dominates, then the direction of polarization is parallel to the clearcoat surface; otherwise it is perpendicular to the surface. In those spectral regions where the paint-scattered light makes a considerable contribution to the net polarization, the net degree of linear polarization of the returned light is reduced or even abolished.

It follows that the light reflected from cars with shiny, smooth clearcoat and red paintwork, for example, is less polarized in the red spectral range and the degree of linear polarization of reflected light is highest in the blue and ultraviolet range of the spectrum if the paint layer absorbs ultraviolet light. The considerably reduced amount of paint-scattered light for the shorter wavelengths causes the red bodywork to be dark and strongly polarized in the blue and ultraviolet region of the spectrum. For longer wavelengths, green and especially red, the amount of light emanating from the red paint below the transparent clearcoat is greater, and so the net degree of linear polarization is reduced in the red and green spectral range. This is the reason for the general rule that in a given spectral region the darker objects polarize light to a higher degree if the illuminating light is unpolarized and white, like sunlight.

Mizera et al. (2001) discussed the differences in the reflection polarization between metallized and non-metallized paints of car bodies. The metallized paints influence the polarization of reflected light as do non-metallized paints because of the transparent non-metallic clearcoat. However, the reflectivity of metallized paints is high over a relatively wide spectral range, in which the degree of linear polarization of reflected light is considerably reduced, as we have mentioned above. Hence, the bodywork of cars with metallized paint possess low degrees of linear polarization in the wide spectral region, where the metal particles reflect light efficiently.

Comparing the reflection-polarization patterns of the passenger vehicle above which the dragonflies were observed with those of water bodies (Horváth 1995; Horváth & Varjú 1997; Gál et al. 2001; Bernáth et al. 2004) we conclude that the car body perfectly mimicked the optical characteristics of flat surface of dark waters and therefore attracted sexually actives males of *L. depressa*.

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References

Bernáth, B., G. Szedenics, G. Molnár, G. Kriska & G. Horváth, 2001. Visual ecological impact of "shiny black anthropogenic products" on aquatic insects: oil reservoirs and plastic sheets as polarized traps for insects associated with water. Archives of Nature Conservation and Landscape Research 40: 89-109.

Bernáth, B., G. Szedenics, H. Wildermuth & G. Horváth, 2002. How can dragonflies discern bright and dark waters from a distance? The degree of polarization of reflected light as a possible cue for dragonfly habitat selection. Freshwater Biology 47: 1707-1719.

Bernáth, B., J. Gál & G. Horváth, 2004. Why is it worth flying at dusk for aquatic insects? Polarotactic water detection is easiest at low solar elevations. Journal of Experimental Biology 207: 755-765.

Fernando, C.H., 1958. The colonization of small freshwater habitats by aquatic insects. 1. General discussion, methods and colonization in the aquatic Coleoptera. Ceylon Journal of Science (Biological Sciences) 1: 116-154.

Gál, J., G. Horváth & V.B. Meyer-Rochow, 2001. Measurement of the reflection-polarization pattern of the flat water surface under a clear sky at sunset. Remote Sensing of Environment 76: 103-111.

Günther, A., 2003. Eiablage von *Sympetrum vulgatum* auf ein parkendes Auto (Odonata: Libellulidae). Libellula 22: 19-23.

Horváth, G., 1995. Reflection-polarization patterns at flat water surfaces and their relevance for insect polarization vision. Journal of Theoretical Biology 175: 27-37.

Horváth, G. & D. Varjú, 1997. Polarization pattern of freshwater habitats recorded by video polarimetry in red, green and blue spectral ranges and its relevance for water detection by aquatic insects. Journal of Experimental Biology 200: 1155-1163.

Horváth, G. & D. Varjú, 2003. Polarized light in animal vision – polarization patterns in nature. Springer, Heidelberg & Berlin & New York.

Horváth, G. & J. Zeil, 1996. Kuwait oil lakes as insect traps. Nature 379: 303-304.

Horváth, G., B. Bernáth & G. Molnár, 1998. Dragonflies find crude oil visually more attractive than water: multiple-choice experiments on dragonfly polarotaxis. Naturwissenschaften 85: 292-297.

Mizera, F., B. Bernáth, G. Kriska & G. Horváth, 2001. Stereo videopolarimetry: measuring and visualizing polarization patterns in three dimensions. Journal of Imaging Science and Technology 45: 393-399.

Popham, E.J., 1964. The migration of aquatic bugs with special reference to the Corixidae (Hemiptera Heteroptera). Archiv für Hydrobiologie 60: 450-496.

Schmidt, E., 2001. Der Plattbauch *Platetrum depressum* (L., 1758) (Odonata), das Insekt des Jahres 2001. Entomologische Nachrichten und Berichte 45: 1-8.

Schwind, R., 1991. Polarization vision in water insects and insects living on a moist substrate. Journal of Comparative Physiology (A) 169: 531-540.

Schwind, R., 1995. Spectral regions in which aquatic insects see reflected polarized light, Journal of Comparative Physiology (A) 177: 439-448.

Sternberg, K., 2000. *Libellula depressa* Linnaeus, 1758. In: Sternberg, K. & R. Buchwald (eds) "Die Libellen Baden-Württembergs. Band 2: Großlibellen (Anisoptera), Literatur", Ulmer, Stuttgart, pp. 436-448.

Stevani, C.V., J.S. Porto, D.J. Trindade & E.J.H. Bechara, 2000a. Automotive clearcoat damage due to oviposition of dragonflies. Journal of Applied Polymer Science 75: 1632-1639.

Stevani, C.V., D.L. A. Faria, J.S. Porto, D.J. Trindade & E.J.H. Bechara, 2000b. Mechanism of automotive clearcoat damage by dragonfly eggs investigated by surface enhanced Raman scattering. Polymer Degradation and Stability 68: 61-66.

Svihla, A., 1961. An unusual ovipositing activity of *Pantala flavescens* Fabricius. Tombo 4: 18.

Torralba Burrial, A. & F.J. Ocharan, 2003. ¿Coches como hábitat para libélulas? Algunos machos de *Crocothemis erythraea* creen que sí. Boletin de la Sociedad Entomologia Aragonesa 32: 214-215.

Watson, J.A.L., 1992. Oviposition by exophytic dragonflies on vehicles. Notulae Odonatologicae 3: 137.

Wildermuth, H., 1998. Dragonflies recognize the water of rendezvous and oviposition sites by horizontally polarized light: a behavioural field test. Naturwissenschaften 85: 297-302.

Wyniger, R., 1955. Beobachtungen über die Eiablage von *Libellula depressa* L. (Odonata, Libellulidae). Mitteilungen der Entomologischen Gesellschaft Basel NF 5: 62-63.