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Why do red and dark-coloured cars lure aquatic insects? The attraction of water insects to car paintwork explained by reflection–polarization signals

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We reveal here the visual ecological reasons for the phenomenon that aquatic insects often land on red, black and dark-coloured cars. Monitoring the numbers of aquatic beetles and bugs attracted to shiny black, white, red and yellow horizontal plastic sheets, we found that red and black reflectors are equally highly attractive to water insects, while yellow and white reflectors are unattractive. The reflection–polarization patterns of black, white, red and yellow cars were measured in the red, green and blue parts of the spectrum. In the blue and green, the degree of linear polarization p of light reflected from red and black cars is high and the direction of polarization of light reflected from red and black car roofs, bonnets and boots is nearly horizontal. Thus, the horizontal surfaces of red and black cars are highly attractive to red-blind polarotactic water insects. The p of light reflected from the horizontal surfaces of yellow and white cars is low and its direction of polarization is usually not horizontal. Consequently, yellow and white cars are unattractive to polarotactic water insects. The visual deception of aquatic insects by cars can be explained solely by the reflection–polarizational characteristics of the car paintwork.

Keywords: polarization vision; polarotaxis; aquatic insects; visual deception; car paintwork; visual ecology

1. INTRODUCTION

Aquatic insects are frequently observed to land on red cars (Jäch 1997; Nilsson 1997; Kriska *et al.* 1998; Vondel 1998; Bernáth *et al.* 2001), which was explained by the shiny appearance or the red colour of the car-body (Jäch 1997; Nilsson 1997), or was considered enigmatic (Vondel 1998). Water insects (e.g. Coleoptera and Heteroptera) often swarm in large numbers, mate above and land on the roofs, bonnets and boots of black or red cars and Ephemeroptera and Odonata females often lay their eggs *en masse* on these car surfaces (figure 1). Although different insect species associated with water, especially dragonfly species (Wyniger 1955; Svihla 1961; Watson 1992; Wildermuth 1998; Stevani *et al.* 2000*a*,*b*; Bernáth *et al.* 2001; Günther 2003; Torralba & Ocharan 2003; Wildermuth & Horváth 2005) have been observed to swarm above cars, in particular the landing of water insects on red cars has drawn the attention of the community of researchers studying water insect migration (Jäch 1997; Nilsson 1997; Vondel 1998). To reveal the visual ecological reasons for this phenomenon, we monitored the numbers of aquatic beetles (Coleoptera) and bugs (Heteroptera) attracted to horizontal shiny red, yellow, white and black plastic sheets. Since aquatic insects detect water by means of the high and horizontal polarization of light reflected from the water surface (Schwind 1991, 1995), we measured the reflection–polarizational characteristics of red, yellow, white and black cars in the red, green and blue parts of the spectrum. On the basis of these field experiments and polarization measurements, we provide here a novel solution to the previously perplexing question of why red cars attract aquatic insects. We show that the visual deception of aquatic insects by red cars can be explained solely by the reflection–polarizational characteristics of car-bodies. Considering water insect protection in wetland habitats, we discuss the question: what is the environmentally friendly colour of cars?

2. MATERIAL AND METHODS

Our field experiment was performed in the Hungarian Hortobágy National Park, on the shore of Hagymás-basin marsh (47°33′29″ N, 20°55′29″ E; 10×10 km Universal Transverse Mercator (UTM) grid code: DT 96) characterized by patchy vegetation with a rich and diverse aquatic insect community. The area of the Hagymás-basin was 0.3 km^2 and the depth of water ranged between 25 and 60 cm. Aquatic insects were captured by shiny, non-transparent black, red, yellow and white plastic sheets (test surfaces) laid onto the ground. In a previous pilot experiment, we ascertained that horizontal matt black, red, yellow and white clothes did not attract aquatic insects. This control experiment demonstrated well that the water insects deceived by the four differently coloured shiny plastic sheets were attracted by the polarization rather than by the colour and/or

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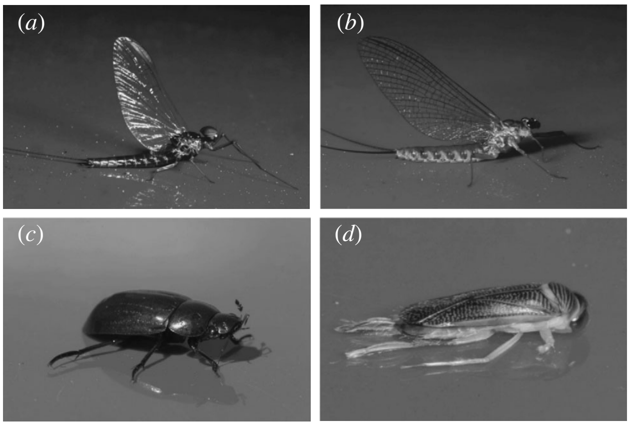

Figure 1. Insects associated with water landing on the roof of a red car. (*a*) A mayfly, Baetidae sp. (*b*) Another mayfly, Ecdyonuridae sp. (*c*) A water beetle, *Hydrochara caraboides*. (*d*) A water bug, *Sigara striata*. The insects were observed and photographed in April and May of 2005 in Hungary on the roof of the same red car (Daewoo Matiz).

intensity of reflected light. It has been shown also in numerous earlier field experiments (Horváth & Varjú 2003) that the horizontal polarization of reflected light is the major optical cue that attracts water insects to shiny surfaces.

The four shiny plastic test surfaces of $9\times3\ \mathrm{m}^2$ were placed 30 m from the shoreline of the water and 30 m from each other. They were pinned to the ground with tent-pegs. The investigation was carried out between 18 and 21 h (local summer time = Universal Time Coordinated (UTC) + 2) on 4 August 2004. Sampling hours were chosen according to the optimal periods for flight of aquatic insects. Samples were taken hourly continuously throughout a 3 h period. All insects were collected manually from the test surfaces by capturing them with insect aspirators (smaller insects) or hand-nets (larger insects). The captured insects were preserved in glass vials filled with 70% ethanol and identified later in the lab. Species richness and the number of individuals were compared by statistical analysis of covariance (ANCOVA) and *post hoc* Tukey honestly significant difference (HSD) tests. Composition of insects captured on the test surfaces was studied by cluster analysis. Species composition based on presence–absence data was compared by the Sørensen index, and the statistical dissimilarity in abundance data was compared by the Bray-Curtis index (Legendre & Legendre 1998).

The reflection–polarization patterns of a black, a white, a yellow and a red car (Suzuki swift) were measured on 4 April 2005 in Budapest, Hungary (47°32′ N, 19°4′ E) at 10.30 h solar time (local summer time = UTC + 2) on a sunny day under a clear, cloudless sky by videopolarimetry in the blue (B), green (G) and red (R) parts of the spectrum at $\lambda_B = 450 \pm 40$ nm (wavelength of maximal sensitivity ± half bandwidth of the camera's charge coupled device (CCD) sensors), $\lambda_G = 550 \pm 40$ nm and $\lambda_R = 650 \pm 40$ nm. The method of videopolarimetry is described in detail elsewhere (Horváth & Varjú 1997). The cars were illuminated from the left-hand side by the sun at a solar zenith angle of 42°. The long axis of the cars and the viewing direction of the polarimeter were perpendicular to the solar meridian. The angle of declination of the optical axis of the polarimeter was −20° from the horizontal. The measurement of the reflection–polarization patterns of all four cars were made during about 15 min, thus the illumination conditions (the solar position) were practically the same. The cars had been stored for several months in the open air, and they were neither washed nor waxed before being measured. Thus, they were medium dirty.

Table 1. Number of individuals of the 37 taxa captured on our horizontal shiny plastic sheets of different colours.

	plastic sheet				
captured taxa	black	red	yellow	white	Σ
Anacaena limbata	5	3	0	0	8
Berosus luridus	5	4	0	0	9
Berosus signaticollis	3	3	0	0	6
Bidessus nasutus	0	1	0	0	1
Bidessus unistriatus	2	1	0	0	3
Cymbiodyta marginella	3	9	0	0	12
Dryops species	1	0	0	0	1
Enochrus affinis	12	11	0	0	23
Enochrus bicolor	0	0	0	1	1
Enochrus coarctatus	0	2	0	0	2
Enochrus quadripunctatus	11	51	0	0	62
Graptodytes bilineatus	21	53	0	0	74
Haliplus fluviatilis	6	3	0	0	9
Haliplus immaculatus	1	0	0	0	1
Haliplus ruficollis	1	2	0	0	3
Helochares lividus	2	5	0	0	7
Helochares obscurus	10	19	0	0	29
Helophorus species	248	437	42	12	739
Hydrobius fuscipes	0	5	0	0	5
Hydrochara flavipes	0	1	0	1	2
Hydrochus flavipennis	1	1	0	0	2
Hydroglyphus pusillus	21	16	5	1	43
Hygrotus decoratus	1	0	0	0	1
Hygrotus impressopunctatus	2	2	0	0	4
Hygrotus inaequalis	0	1	0	0	1
Laccophilus minutus	1	1	0	1	3
Limnoxenus niger	2	2	0	0	4
Peltodytes caesus	1	1	0	0	2
Porhydrus obliquesignatus	0	1	0	0	1
Rhantus suturalis	0	0	1	0	1
Cymatia rogenhofferi	2	1	0	0	3
Callicorixa praeusta	0	0	0	1	1
Hesperocorixa linnaei	2	2	0	0	4
Paracorixa concinna	0	0	0	1	1
Sigara falleni	3	3	0	9	15
Sigara lateralis	30	59	40	16	145
Sigara striata	1	0	0	0	1
Σ	398	700	88	43	1229

3. RESULTS

One thousand two hundred and twenty nine (1059 Coleoptera and 170 Heteroptera) aquatic insect specimens were captured, representing 30 Coleoptera and 7 Heteroptera taxa (table 1). The black and red plastic sheets provided huge numbers of individuals and taxa compared to the yellow and white ones. The black and red plastic sheets were characterized by high numbers of individuals (up to 596 specimens) and diverse species composition (up to 27 taxa), while white and yellow plastics provided small numbers of individuals (up to 51 specimens) and only a few taxa (up to 8). Although the red plastic attracted more individuals than the black one (table 1), there were no statistically significant differences in the numbers of individuals and taxa between the black and red sheets. In the number of individuals, there were marginally significant

Table 2. Results of ANCOVA and *post hoc* Tukey HSD test for comparison of numbers of species and numbers of individuals captured on the horizontal shiny plastic sheets of different colours. (*significant differences, $p<0.05$.)

		number of individuals (ANCOVA: d.f.$_{\text{effect}}=3$, MS$_{\text{effect}}=0.9179$, MS$_{\text{error}}=0.3357$, $F=27.3451$, $p=0.0003^*$)			
		black	red	yellow	white
number of species (ANCOVA: d.f.$_{\text{effect}}=3$, MS$_{\text{effect}}=0.3565$, MS$_{\text{error}}=0.0208$, $F=17.1620$, $p=0.0013^*$)	black	—	$p=0.9594$	$p=0.0214^*$	$p=0.0008^*$
	red	$p=0.9993$	—	$p=0.0120^*$	$p=0.0006^*$
	yellow	$p=0.0071^*$	$p=0.0062^*$	—	$p=0.0452^*$
	white	$p=0.0062^*$	$p=0.0054^*$	$p=0.9992$	—

differences between yellow and white sheets, but the number of species was not significantly different (table 2, figure 2). The attractiveness of the yellow and white sheets was statistically significantly lower than that of the red and black ones. Hence, there was a remarkable dissimilarity between the red/black and the white/yellow pairs both in the abundance data and species richness (figure 2).

The degree of linear polarization p of light reflected from the bonnet of the white car was very low (2–6%) and the direction of polarization of reflected light was not horizontal (figure 3, table 3). Unlike the white car, the p of light reflected from the black car was high (49–54%) and the direction of polarization was nearly horizontal. The reflection–polarizational characteristics of white and black cars were practically independent of the wavelength, since the paints of these cars were colourless. On the other hand, the reflection–polarization patterns of the yellow and red cars were wavelength dependent. The p of light reflected from the bonnet of the yellow car was low, it was lowest (3%) in the red and highest (12%) in the blue, and the direction of polarization was nearly horizontal only in the blue (figure 3, table 3). The p of light reflected from the red car was low (10%) in the red part of the spectrum, while it was high (42–52%) in the green and blue. The direction of polarization of light reflected from the red car was nearly horizontal in the green and blue, but it was not horizontal in the red. The same was true for the reflection–polarizational characteristics of the black, white, red and yellow horizontal plastic sheets used in our water insect monitoring field experiment.

All other more or less horizontal car surfaces (roof and boot) possessed the same reflection–polarizational characteristics as those of the bonnet. The direction of polarization of light reflected from the tilted windscreen and the more or less vertical side walls and windows of the car was nearly horizontal only if the plane of reflection was nearly vertical, i.e. the incident light came from above. In figure 3, this is the case for the windscreen reflecting the downwelling skylight. Although the polarization of light reflected from car-bodies depends on the illumination conditions, figure 3 and table 3 represent well the typical reflection–polarizational characteristics of white, black, yellow and red car bonnets.

The above results are independent of the direction of view: the reflection–polarizational characteristics of nearly horizontal bonnets, roofs and boots of cars are similar for all possible views of flying insects approaching such targets.

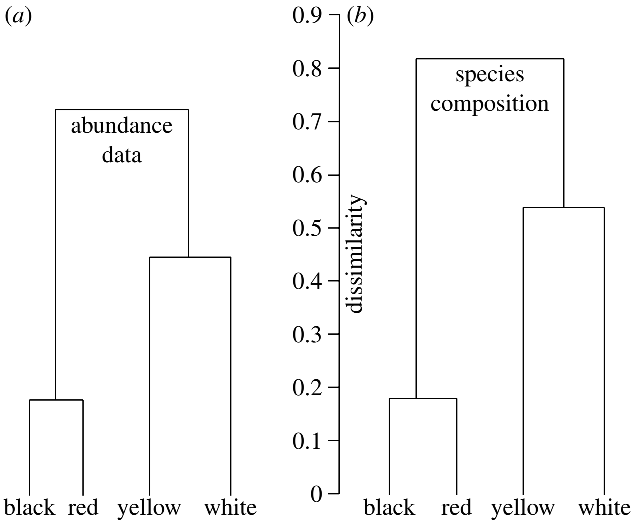

Figure 2. Statistical dissimilarity in insects captured on differently coloured shiny horizontal plastic sheets based on cluster analyses of (*a*) abundance data compared by the Bray–Curtis-index (complete linkage method) and (*b*) species composition compared by the Sørensen index (complete linkage method).

4. DISCUSSION AND CONCLUSION

Although polarimetry was undertaken with only one view of the cars, figure 3 demonstrates well the typical polarizational characteristics of car surfaces: the bodywork of cars reflects linearly polarized light, the direction and degree of polarization of which depend on the orientation and colour of the car surface. Since aquatic insects detect water on the basis of the horizontal polarization of light reflected from water surfaces (Schwind 1991, 1995), the nearly horizontal polarization of light reflected from car-bodies is enough to explain the phenomenon that polarotactic water-seeking insects are deceived by and attracted to the roofs, bonnets and boots of certain (e.g. red, black and any dark-coloured) cars. These parts of the bodywork mimic a water surface for the polarization-sensitive visual system of these insects, for which a horizontally polarized light source is the more attractive, the higher the degree of linear polarization (Schwind 1991, 1995; Horváth & Varjú 2003). Our results are supported by the results of Schwind (1991, 1995), who found that horizontal glass panes underlaid by black and red clothes were highly attractive to some water insects, while glass panes underlaid by white and yellow clothes were unattractive. Nevertheless, beside polarotaxis the preference of the red colour by certain insects associated with water (e.g. dragonflies) cannot be excluded in this visual phenomenon.

In large parking lots, the visual deception of water insects by the carbody can increase significantly, because the cars park close to each other and their polarizing effects

Table 3. Degree of linear polarization p (%) and angle of polarization α (with respect to the vertical) of light reflected from the bonnet of a white, black, yellow and red car (Suzuki Swift) measured by imaging polarimetry in the red (650 nm), green (550 nm) and blue (450 nm) parts of the spectrum. The mean $\pm$ standard deviation of p and α are given for the rectangular areas demarcated by white or black line in figure 2 and involving the car bonnet.

		car			
spectral range	optical variable	white	black	yellow	red
red (650 nm)	p (%)	5.8 ± 2.1	48.9 ± 10.5	3.1 ± 1.8	9.6 ± 4.6
	α (°)	140.4 ± 11.6	91.7 ± 8.6	63.1 ± 56.1	78.0 ± 26.5
green (550 nm)	p (%)	2.3 ± 1.5	50.0 ± 9.3	3.3 ± 1.7	42.4 ± 14.8
	α (°)	59.5 ± 47.3	91.7 ± 7.9	63.9 ± 43.1	88.3 ± 11.4
blue (450 nm)	p (%)	2.9 ± 1.6	54.4 ± 10.3	11.8 ± 3.6	52.4 ± 16.2
	α (°)	71.3 ± 34.5	92.1 ± 7.6	89.2 ± 14.6	91.0 ± 9.76

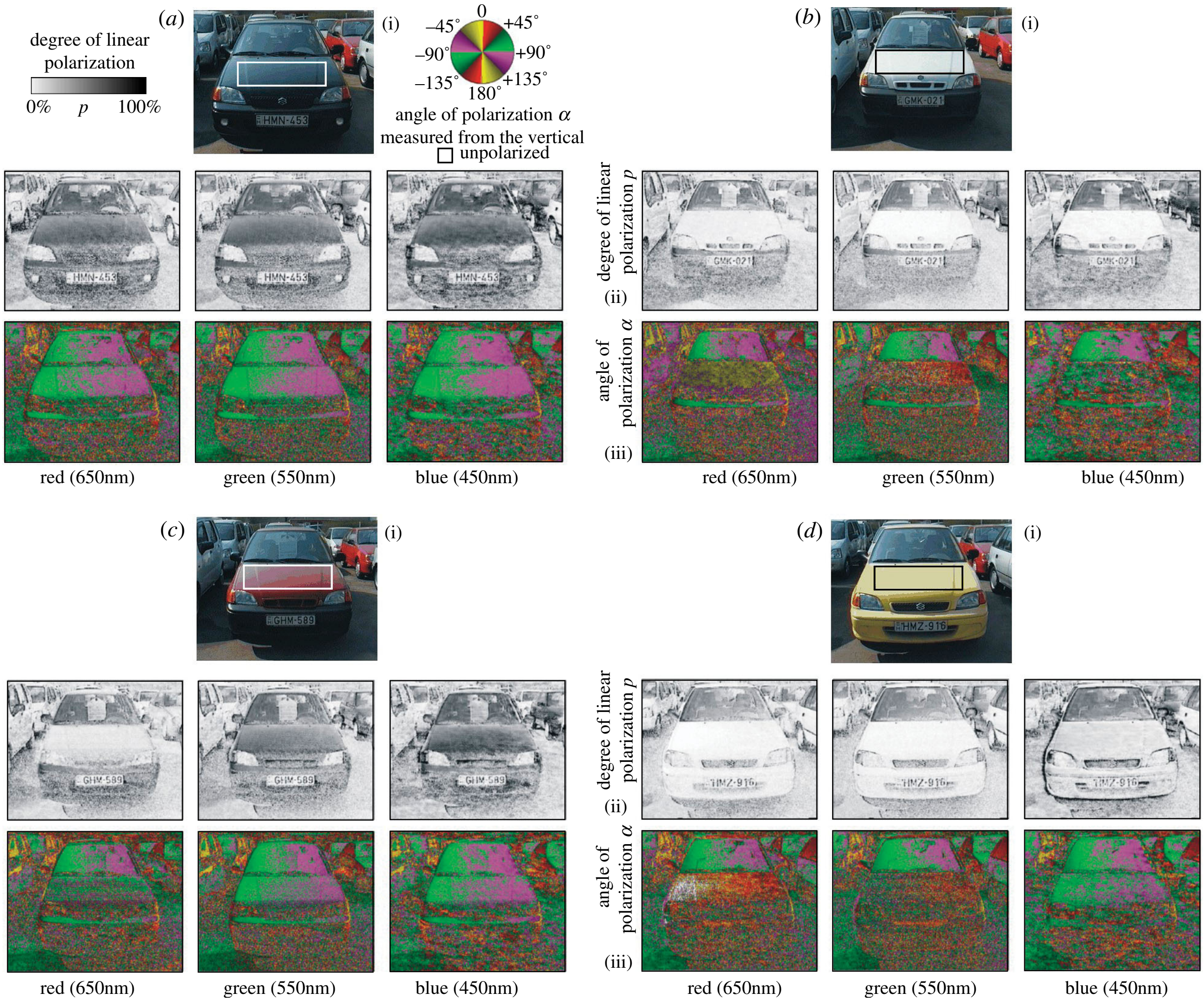

Figure 3. Reflection–polarization patterns of a (*a*) black, (*b*) white, (*c*) red and (*d*) yellow car (Suzuki Swift) measured by imaging polarimetry in the red (650 nm), green (550 nm) and blue (450 nm) parts of the spectrum under a clear sky at a solar zenith angle of 42°. The cars were illuminated from the left-hand side by the sun. The long axis of the cars and the viewing direction of the polarimeter were perpendicular to the solar meridian. The angle of declination of the optical axis of the polarimeter was $-20°$ from the horizontal. (i) Colour picture of the cars. The rectangles show the areas (bonnets) for which the mean and standard deviation of the degree of linear polarization p and angle of polarization α in table 3 are given. Patterns of p (ii) and α (iii) of light reflected from the car-bodies.

are summed, thus forming an ecological trap. This phenomenon is very harmful near nature conservation areas including any kinds of wetlands. An egg-packet of a female mayfly, e.g. contains 6000–9000 eggs (Kriska *et al.* 1998). All the eggs laid onto car surfaces perish. This also often occurs in the case of water insect imagoes, due to dehydration on hot car surfaces (G. Kriska, Z. Csabai, P. Boda, P. Malik & G. Horváth, personal observations). On the other hand, white and yellow (or more generally, brightly coloured) cars have never been observed to lure water insects. Consequently, in relation to water insect protection, these bright-coloured cars can be considered as 'environmentally friendly' (i.e. friendly to aquatic insects). Although it would be a utopian idea to permit only the parking of cars with such colours, nature-lovers could choose such environmentally friendly colours for their cars. We propose that visitors to wetland habitats should drive light-coloured cars, to avoid egg loss by confused water insects. This would be particularly important for Ephemeroptera survival because mayflies are endangered all over the world. Due to depolarization by diffuse reflection, very dirty cars reflect light with much lower degrees of polarization than recently washed and/or waxed shiny cars. Thus, the most environmentally friendly car of all would be one that never gets washed. Figure 3 represents the typical reflection–polarization patterns of medium dirty cars.

The observation that polarizing car surfaces of red, black and dark colours are more or less friendly to polarotactic aquatic insects would deserve further consideration if it could be shown that this phenomenon is important to the survival of populations of such insects. The use of huge horizontal shiny black plastic sheets in agriculture may be more problematic in the protection of insect populations of wetlands, but note that the number of highly polarizing (red, black and dark-coloured) cars is enormous in the world. The study of this problem would be an important task in the future. It has been demonstrated several times (Wyniger 1955; Horváth & Zeil 1996; Kriska *et al*. 1998; Bernáth *et al*. 2001; Günther 2003; Horváth & Varjú 2003; Wildermuth & Horváth 2005) that even relatively small, but highly and horizontally polarizing artificial surfaces (e.g. oil spills, asphalt surfaces, plastic sheets) can be very dangerous for polarotactic water insects.

Finally, we mention that not only the highly and horizontally polarizing car paintworks can be dangerous to water insects and/or their eggs, but the eggs laid onto carbodies can also damage the resin of the clearcoat as does acid rain. It was shown (Stevani *et al*. 2000*a*,*b*) that the eggs of *Miathyria*, *Tauriphila* and *Erythemis* dragonflies at temperatures between 50 and 92 °C produce sulphonic acids that destroy the clearcoat.

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