Experimental Study of Linear and Circular Polarization Sensitivity in Different Insect Species, Especially in Horseflies and Scarab Beetles

Summary of Ph.D. Thesis

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1. Introduction

Tabanid flies can cause severe problems for humans and livestock because of the pathogens of dangerous diseases vectored by the haematophagous tabanid females in the warmer regions of almost all continents. Thus, effective tabanid traps are in large demand, especially in horse and cattle farms. On the other hand, tabanids are pollinators of different plants, and there are numerous predator species which feed on them.

We have shown that both female and male tabanids have positive polarotaxis, that is are attracted to horizontally polarized light, just like many other aquatic insect species. Based on this attraction, I proposed a new concept of tabanid traps consisting of horizontally polarizing photovoltaics. Section 3 of my thesis deals with this novel trap type.

Recently, it was shown that polarotactic tabanids find striped patterns much less attractive than homogeneous ones. This phenomenon gave me the inspiration to study the attractiveness to tabanids of spotty coat patterns, which are widespread among mammals. This subject is treated in section 1 of my thesis.

Similarly to other ungulates, zebras emit carbon dioxide via their breath, and ammonia associated with their urine. These chemicals are strongly attractive to tabanid flies, and therefore are frequently used in tabanid traps. Thus, the question arises, whether the weak optical tabanid-attractiveness of striped coat patterns can be overcome by the olfactory attractiveness. In section 2 of my thesis, I answered this question.

The concept of polarized light pollution has been introduced a few years ago, and it has been shown that shiny dark surfaces (e.g., smooth black car bodies) can function as ecological traps, since they deceive and attract polarotactic water-seeking insects with their horizontally and strongly polarized reflected light. A general way to decrease this polarotactic attractiveness of shiny black artificial surfaces is to decrease the degree of polarization of reflected light. Nowadays, matt paintings of black/grey car-bodies is a fashion fad. I tested, how this mattness influences the polarotactic attractiveness to different aquatic insects. Section 4 of my thesis is devoted to the polarized light pollution of matt black/grey cars.

The strongest known circular polarization of biotic origin is the left-circularly polarized light reflected from the metallic shiny exocuticle of certain scarab beetles of the family

Scarabaeidae. This phenomenon has been discovered by Michelson in 1911. Since this discovery it has been supposed that scarab beetles, reflecting left-circularly polarized light in an optical environment being deficient in circular polarization, may also be able to perceive and use it to find each other (mate/conspecifics). In section 5 of my thesis, I tested this 100-year-old hypothesis in choice experiments with four different scarab species.

2. Materials and Methods

In my Ph.D. thesis, I present the results of several field and laboratory experiments, in which I studied the linear and circular polarization sensitivity in certain species of tabanid flies, mayflies, dolichopodid flies and scarab beetles. Using imaging polarimetry in the red (650 ± 40 nm = wavelength of maximal sensitivity ± half bandwidth of the CCD detectors of the polarimeter), green (550 ± 40 nm) and blue (450 ± 40 nm) parts of the spectrum, I measured the reflection-polarization characteristics of the test surfaces, visual targets and tabanid traps used in these experiments. The measured polarization patterns were practically independent of the spectral range, since the used test objects/surfaces were mainly colourless (black, grey, white, dark brown).

During the field experiments, the body of tabanids trapped by the sticky test surfaces and traps suffered serious damages during their removal, or due to the mechanical hit of the rotating wire of the trap based on a photovoltaic solar panel. These made the taxonomic identification of tabanids impossible. They were, however, visually identified as tabanid flies (Diptera: Tabanidae). In some field experiments the taxonomical identification of tabanids was possible. Then this task was performed by two tabanid experts (Mónika Gyurkovszky and Prof. Róbert Farkas, Department of Parasitology and Zoology, Faculty of Veterinary Science, Szent István University, Budapest).

Due to the used experimental method, the mayflies and dolichopodid flies could not be taxonomically identified, but they surely belonged to the order Ephemoreptera, family Baetidae, Heptageniidae and order Diptera, family Dolichopodidae, respectively, as was visually determined by one of my co-authors (Dr. György Kriska, Biological Institute, Eötvös University, Budapest), who is an expert of these insects.

To establish the significance of observed differences in the experiments, I performed statistical analyses, such as binomial chi-squared, Kruskal-Wallis and Mann-Whitney U tests.

3. Results

3.1. Spottier Targets are Less Attractive to Tabanid Flies: On the Tabanid-Repellency of Spotty Fur Patterns

(3.1.1.) I demonstrated an experimentally supported hypothesis on an earlier unrecognized visual benefit of spotty coat patterns of animals.

(3.1.2.) I showed that the spottiness of the body surface of host animals strongly determines its attractiveness to tabanid flies: the smaller and the more numerous the spots, the less attractive the host is to tabanids.

(3.1.3.) I demonstrated that the attractiveness of spotty patterns to polarotactic tabanids is also reduced, if the target exhibits spottiness only in the pattern of the angle of polarization, while being homogeneous grey with a constant high degree of polarization.

3.2. Stripes Disrupt Odour Attractiveness to Biting Horseflies: Battle Between Ammonia, CO2, and Colour Pattern for Dominance in the Sensory Systems of Host-Seeking Tabanids

(3.2.1.) I examined in the field, how ammonia and CO_2 scents influence the attractiveness to tabanid flies of objects simulating tabanids' host animals with homogeneous black and white as well as zebra-striped surface patterns.

(3.2.2.) I showed that striped targets are significantly less attractive to host-seeking female tabanids than homogeneous white or black ones, even when the targets emit CO_2 and ammonia.

(3.2.3.) I demonstrated that although CO_2 and ammonia increase the number of attracted tabanids, these tabanid-attractive chemicals do not overcome the weak visual attractiveness of stripes to tabanids.

3.3. How Can Horseflies be Captured by Solar Panels? A New Concept of Tabanid Traps Using Light Polarization and Electricity Produced by Photovoltaics

(3.3.1.) I designed a new tabanid trap consisting of a horizontal photovoltaic solar panel which (i) attracts polarotactic tabanid flies with the horizontally polarized light reflected from its shiny black surface, and (ii) supplies electricity for a quickly rotating electric motor with vertical axis of rotation mounted with a horizontally rotating wire that hits and perish the attracted tabanids.

(3.3.2.) In field experiments I measured the tabanid-capturing efficiency of this trap being about 92 % in full sunshine, if the solar elevation angle is not lower than about 29° from the horizon.

(3.3.3.) I found that using a supplementary photovoltaic solar panel (tilted at 45° from the horizontal and oriented towards south-west), the time period during which this tabanid trap works efficiently can be enhanced with two hours, and the efficiency can be increased to 94 %.

3.4. Unexpected Attraction of Polarotactic Water-Leaving Insects to Matt Black Car Surfaces: Mattness of Paintwork Cannot Eliminate the Polarized Light Pollution of Black Cars

(3.4.1.) I showed that the attractiveness of black car-bodies to polarotactic aquatic insects depends in a complex manner on the surface roughness (shiny, matt) and insect species (mayflies, dolichopodid flies, tabanid flies).

(3.4.2.) I found that matt black/grey car-paints can reflect light with such polarization characteristics which can attract polarotactic insects, such as certain mayfly species, for example.

Thus, the polarized light pollution of shiny black cars usually cannot be reduced with the use of matt black painting.

3.5. No Evidence for Behavioral Responses to Circularly Polarized Light in Four Scarab Beetle Species with Circularly Polarizing Exocuticle

(3.5.1.) In eight choice experiments in the field and the laboratory, I tested in four scarab beetle species [*Anomala dubia*, *Anomala vitis* (Coleoptera, Scarabaeidae, Rutelinae) and *Cetonia aurata*, *Potosia cuprea* (Coleoptera,Scarabaeidae, Cetoniinae)] whether they can or cannot perceive circular polarization as it has been believed since 1911, when Michelson has discovered that the exocuticle of certain scarab beetles reflects circularly polarized light.

(3.5.2.) I concluded from the choice experiments that these scarab species are not attracted to circularly polarized light when feeding or looking for mate or conspecifics. By this I refuted experimentally a 100-year-old belief.

4. Publications

4.1. Publications Representing the Basis of the Ph.D. Thesis

[1] **<u>Blahó, M.</u>**; Egri, Á.; Báhidszki, L.; Kriska, G.; Hegedüs, R.; Åkesson, S.; Horváth, G. (2012) Spottier targets are less attractive to tabanid flies: On the tabanid-repellency of spotty fur patterns. *Public Library of Science ONE* (*PLoS ONE*) 7(8): e41138. doi:10.1371/journal.pone.0041138 + supporting information

[2] **<u>Blahó, M.</u>**; Egri, Á.; Száz, D.; Kriska, G.; Åkesson, S.; Horváth, G. (2013) Stripes disrupt odour attractiveness to biting horseflies: Battle between ammonia, CO2, and colour pattern for dominance in the sensory systems of host-seeking tabanids. *Physiology and Behavior* 119: 168-174

[3] **Blahó, M.**; Egri, Á.; Barta, A.; Antoni, G.; Kriska, G.; Horváth, G. (2012) How can horseflies be captured by solar panels? A new concept of tabanid traps using light polarization and electricity produced by photovoltaics. *Veterinary Parasitology* 189: 353-365

[4] **Blahó, M.**; Herczeg, T.; Kriska, G.; Egri, Á.; Száz, D.; Farkas, A.; Tarjányi, N.; Czinke, L.; Barta, A.; Horváth, G. (2014) Unexpected attraction of polarotactic water-leaving insects to matt black car surfaces: Mattness of paintwork cannot eliminate the polarized light pollution of black cars. *Public Library of Science ONE* (*PLoS ONE*) 9 (7): e103339 + electronic supplement (doi: 10.1371/journal.pone.0103339)

[5] **Blahó, M.**; Egri, Á.; Hegedüs, R.; Jósvai, J.; Tóth, M.; Kertész, K.; Biró, L. P.; Kriska, G.; Horváth, G. (2012) No evidence for behavioral responses to circularly polarized light in four scarab beetle species with circularly polarizing exocuticle. *Physiology and Behavior* 105: 1067-1075 + electronic supplement

4.2. Additional Publications Relating to the Ph.D. Thesis

[E-1] Horváth, G.; **Blahó, M.**; Kriska, G.; Hegedüs, R.; Gerics, B.; Farkas, R.; Akesson, S. (2010) An unexpected advantage of whiteness in horses: The most horsefly-proof horse has a depolarizing white coat. *Proceedings of the Royal Society B* 277: 1643-1650

[E-2] Horváth, G.; **Blahó, M.**; Egri, Á.; Kriska, G.; Seres, I.; Robertson, B. (2010) Reducing the maladaptive attractiveness of solar panels to polarotactic insects. *Conservation Biology* 24: 1644-1653 + electronic supplement

[E-3] Egri, Á.; **Blahó, M.**; Kriska, G.; Farkas, R.; Gyurkovszky, M.; Åkesson, S.; Horváth, G. (2012) Polarotactic tabanids find striped patterns with brightness and/or polarization modulation least attractive: An advantage of zebra stripes. *Journal of Experimental Biology* 215: 736-745 + electronic supplement

[E-4] Egri, Á.; **<u>Blahó, M.</u>**; Sándor, A.; Kriska, G.; Gyurkovszky, M.; Farkas, R.; Horváth, G. (2012) New kind of polarotaxis governed by degree of polarization: Attraction of tabanid flies to differently polarizing host animals and water surfaces. *Naturwissenschaften* 99: 407-416

[E-5] Egri, Á.; **<u>Blahó, M.</u>**; Száz, D.; Barta, A.; Kriska, G.; Antoni, G.; Horváth, G. (2013) A new tabanid trap applying a modified concept of the old flypaper: Linearly polarising sticky black surfaces as an effective tool to catch polarotactic horseflies. *International Journal for Parasitology* 43: 555-563 + supporting information

[E-6] Egri, Á.; **<u>Blahó, M.</u>**; Száz, D.; Kriska, G.; Majer, J.; Herczeg, T.; Gyurkovszky, M.; Farkas, R.; Horváth, G. (2013) A horizontally polarizing liquid trap enhances the tabanid-capturing efficiency of the classic canopy trap. *Bulletin of Entomological Research* 103: 665-674

[E-7] Boda, P.; Horváth, G.; Kriska, G.; **<u>Blahó, M.</u>**; Csabai, Z. (2014) Phototaxis and polarotaxis hand in hand: Night dispersal flight of aquatic insects distracted synergistically by light intensity and reflection polarization. *Naturwissenschaften* 101: 385-395 + electronic supplement

[E-8] Herczeg, T.; **<u>Blahó, M.</u>**; Száz, D.; Kriska, G.; Gyurkovszky, M.; Farkas, R.; Horváth, G. (2014) Seasonality and daily activity of male and female tabanid flies monitored in a Hungarian hill-country pasture by new polarization traps and traditional canopy traps. *Parasitology Research* 113 (11): 4251-4260 (doi: 10.1007/s00436-014-4103-6)

[E-9] Herczeg, T.; Száz, D.; **<u>Blahó, M.</u>**; Barta, A.; Gyurkovszky, M.; Farkas, R.; Horváth, G. (2015) The effect of weather variables on the flight activity of horseflies (Diptera: Tabanidae) in the continental climate of Hungary. *Parasitology Research* 114 (3): 1087-1097 (doi: 10.1007/s00436-014-4280-3)

[H-1] **<u>Blahó M.</u>**, Horváth G., Hegedüs R., Kriska Gy., Gerics B., Farkas R., S. Akesson (2010) A lovak fehérségének egy nem várt előnye: A leginkább ”bögölyálló” ló depolarizáló fehér szőrű, a fekete ló pedig szenvedi a polarizáló szőrét. *Fizikai Szemle* 60: 145-155 + címlap

[H-2] **<u>Blahó M.</u>**, Egri Á., Báhidszki L., Kriska Gy., Hegedüs R., S. Akesson, Horváth G. (2012) A foltos kültakaró előnye. *Természet Világa* 143: 265-268

[H-3] **<u>Blahó M.</u>**, Egri Á., Horváth G., Hegedüs R., Kriska Gy., Jósvai J., Tóth M., Kertész K., Biró L. P. (2012) A cirkulárisan fénypolarizáló szkarabeuszok nem reagálnak a cirkuláris polarizációra: Egy évszázados biooptikai hipotézis cáfolata. I. + II. rész *Fizikai Szemle* 62: 217-221 + 294-298 + I.-IV. belső színes oldalak

[H-4] **<u>Blahó M.</u>**, Egri Á., Horváth G., Barta A., Antoni Gy., Kriska Gy. (2013) Hogyan fogható napelemmel bögöly? Fénypolarizációra és fotoelektromosságra épülő új rovarcsapda, avagy alapkutatásból gyakorlati haszon. I. + II. rész. *Fizikai Szemle* 63: 145-149 + 181-187

[H-5] Horváth G., **<u>Blahó M.</u>**, Száz D., Barta A., Farkas R., Gyurkovszky M. (2014) Bögölycsapda poláros fénnyel. I. rész: A bögölypapír. *Természet Világa* 145: 115-119

[H-6] **<u>Blahó M.,</u>** Herczeg T., Száz D., Czinke L., Horváth G., Barta A., Egri Á., Farkas A., Tarjányi N., Kriska Gy. (2015) Matt fekete autók poláros fényszennyezése: A matt bevonat sem környezetbarát. I. + II. rész. *Fizikai Szemle* 65: 7-9 + 38-41 + címlap + színes belső borító