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SHORT COMMUNICATION

Do geomagnetic storms change the behaviour of the stingless bee guiruçu (*Schwarziana quadripunctata*)?

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Abstract Six behavioural experiments were carried out to investigate the magnetic field effects on the nest-exiting flight directions of the honeybee *Schwarziana quadripunctata* (*Meliponini*). No significant differences resulted during six experiment days under varying geomagnetic field and the applied static inhomogeneous field (about ten times the geomagnetic field) conditions. A surprising statistically significant response was obtained on a unique magnetic storm day. The magnetic nanoparticles in these bees, revealed by ferromagnetic resonance, could be involved in the observed effect of the geomagnetic storm.

Keywords Stingless bee · Magnetic storm · Magnetic nanoparticles

Introduction

Animal sensitivity studies have revealed a wide range of results correlated to natural environment phenomena, such as earthquakes and tsunamis. Organisms can evolve behaviours that enhance survival and fitness (Kirschvink 2000); many of them involve special pattern recognition abilities. Animal orientation has to be understood based on sensory inputs, motivation, genetic pre-disposition and individual experiences that turn complex the analysis of any single cue.

Magnetoreception plays an important role in animal orientation and navigation (Wiltschko and Wiltschko 1995; Gould 2004). Despite a recent increase in physiological and behavioural studies, it is still poorly understood (Nemec et al. 2005; Wang et al. 2004; Becker and Gerisch 1981; Acosta-Avalos et al. 2001).

Since the first observation of the geomagnetic field influence on *Apis mellifera* dancing (Lindauer and Martin 1968), several behavioural experiments for different magnetic field conditions (Kirschvink et al. 1997 and references therein; Schmitt and Esch 1993) were performed, and the presence of magnetic particles was observed (Gould et al. 1978; Oliveira et al. 2005; El-Jaick et al. 2001), confirming biophysical predictions of a magnetite-based magnetoreceptor.

Magnetic measurements have also shown the presence of magnetic particles in another honeybee specie, *Schwarziana quadripunctata* (Lucano et al. 2006). Here, we report on behavioural fieldwork performed with this bee to examine possible geomagnetic field effects on their nest-exiting angles. For the first time, effects of the geomagnetic field on the bee flight orientation are shown, when on one of the 6 days, a fortuitous magnetic storm occurred. This single event provided a rare observation of magnetically altered behaviour.

Materials and methods

Behavioural experiments were performed with one *S. quadripunctata* underground nest in Teresópolis (22°49′S, 47°06′W), Rio de Janeiro (Atlantic Forest), chosen due to its location, colony size and magnetic conditions (South Atlantic Anomaly [SAA]). The nest entrance was a 2-cm-diameter channel, 30 cm long and oriented about 25° with the vertical in the magnetic west direction. Six experiments were carried out from May to November 2001 under almost

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the same weather conditions: breeze, sunlight, air relative humidity (70 to 90%) and temperature (15 to 19°C). The exiting flying direction of the bees (dip and azimuth angles) was registered by one or two video cameras during 15 to 20 min from 9:50 A.M. to 3 P.M., the period of highest exiting activity (6 bees/min; Imperatriz-Fonseca and Darakjian 1994). The azimuth was recorded with the monitoring camera suspended 40 cm over the nest and the dip with the camera 40 cm from the nest in the east–west direction. The data were collected from a television monitor, copying the bee position frame-by-frame to plastic film, on a straight-line from the nest up to 8 cm. The azimuth was taken relative to the local north–south geomagnetic direction with clockwise positive value from the south and the dip relative to local vertical. Applied field intensities were measured by a portable magnetometer (DM2220 Schonstedt Instruments). Experiments were performed under local geomagnetic (GEO, control) and magnetic applied field (MAG). The spatially inhomogeneous magnetic field, in the magnetic east–west direction, was produced by two magnetic bars both 30 cm from the nest. The intensity ranged from 0.08 to 0.11 mT in the recording region, estimated as 0.17 mT at the nest chamber.

The geomagnetic field is an extremely dynamic phenomenon described by a local vector, with daily and secular variations of magnitude and direction. Magnetic storms are relatively rare worldwide disturbances of the geomagnetic field lasting a few days. The intensities were obtained from data registered by the National Observatory (Vassouras, RJ, Brazil), including the observed magnetic storm.

Unidirectional circular statistics of the azimuth and dip exiting angles were performed with the Oriana® software. The Rayleigh and Watson F-tests (Vassar statistics: critical F values for a significant level $\alpha=0.05$) were performed to evaluate the significance of the circular statistic results.

Results

Table 1 presents the circular statistics results of the exiting angle components. The two first control experiments quantitatively confirmed the visual observation of preferential nest-exiting angles. The mean values of these components are statistically significant ($p<0.001$).

Figure 1 shows the geomagnetic intensity daily variations for the experiment days except for 08/22, where symbols indicate the experiment periods. 11/06 is easily identified as a magnetically anomalous day, classified as a strong magnetic storm (Geophysical Observatory Fürstenfeldbruck, LMU, Munich). When daily intensities are compared, 11/06 presents a 150 nT difference during the experiments (229 nT, maximum variation). Watson F-test between GEO and MAG on the same experiment day showed significantly equal exiting angle values ($p\geq0.14$ and $F\leq2.25$). In contrast, the mean azimuth and dip values of the GEO on the magnetic storm day (11/06) are the only ones distinct from the other GEO experiments ($p<0.001$ and $F>47$). A similar result is obtained for the MAG experiments ($p<0.001$ and $F>30$). The mean dip and azimuth angles as a function of the geomagnetic field intensity for the GEO and MAG conditions are shown in Fig. 2. The notably different magnetic storm data are clearly seen by the dip value, while the azimuth value seems to be less sensitive.

Table 1 Circular statistics parameters of the azimuth (azim) and dip exiting angles for experiments in GEO (control) and MAG setup, all with $p<0.001$ and $r>0.90$

2001 experiment dates							Exiting angles
05/22	05/30	07/09	08/22	09/03	11/06		
145	72	–	136	64	94	n	dip
40°	42°	–	36°	38°	16°	μ	GEO
13°	13°	–	21°	10°	18°	csd	
–	–	–	136	40	105	n	dip
–	–	–	36°	41°	14°	μ	MAG
–	–	–	20°	7°	17°	csd	
54	72	72	147	64	95	n	Azim
215°	231°	242°	235°	205°	256°	μ	GEO
27°	16°	11°	19°	24°	14°	csd	
–	–	51	102	40	102	n	Azim
–	–	245°	234°	208°	258°	μ	MAG
–	–	14°	25°	19°	12°	csd	

n Number of observations, μ mean value, *csd* circular standard deviation

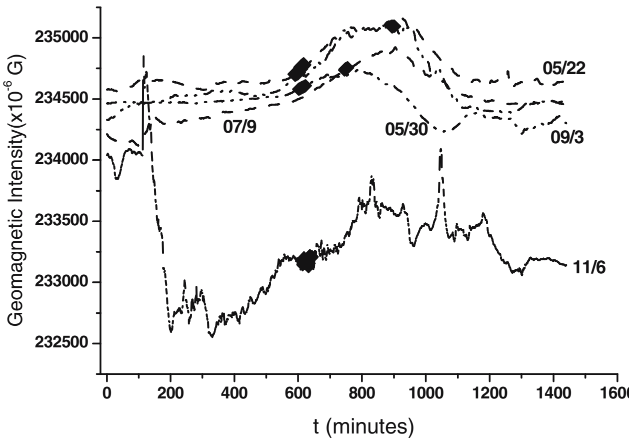

Fig. 1 Daily geomagnetic intensity of each experiment day; experiment periods marked; 08/22 data not registered

Discussion

Although magnetic fields up to ten times the local field were applied to observe effects on the bee mean exiting angles compared to those under geomagnetic fields, the Watson *F*-test of all the mean angles on the same day do not statistically differ. Nevertheless, a magnetic modified flight activity of this nest bee was observed (Nascimento et al. 2001), as in other bees (Martin et al. 1989). On the other hand, Watson *F*-test showed that under most of the geomagnetic conditions, azimuth means are significantly different from one experiment to another, while for dip results, it is not so evident, except for the surprisingly low dip mean angle of the magnetic storm day experiments.

Evidence and characterization of the magnetic material in *S. quadripunctata* body parts were obtained by SQUID magnetometry and ferromagnetic resonance. Under the ferromagnetic hypothesis (Vácha 1997), this material was suggested as a magnetic sensor (Lucano et al. 2006).

These behavioural and physical results suggest that these bees could perceive the anomalous magnetic storm changes. In this case, it would be relevant to perform experiments under simulated magnetic storms since each event of this natural phenomenon is unique and difficult to predict (http://www.chem.hawaii.edu/uham/storm.html).

These few magnetic results open a spectrum of arguments to understand the different magnetic responses. One can consider, for example, the saturation mechanism observed for miracidia larvae of the eyefluke under high static field (7.5 nT; Stabrowski and Nollen 1985). A similar mechanism in the bee behaviour would be activated, with a different value for the field saturation limit, since no effect was observed under the high applied magnetic field. Another assumption is that bees are sensitive to the changes in the magnetic field time pattern rather than to space perturbations. The orientation of pigeons wearing coils generating a uniform field about one sixth of the geomagnetic one resulted greater scattering than for birds with no current (Walcott 1977). Further, no systematic different orientation behaviour or homing performance was observed between pigeons released within the Gershein anomaly (199-nT maximum value) and a control site outside. As suggested for birds, bees could perhaps sense the anomaly in the magnetic field and ignore it, using instead diverse orientation cues (Wiltschko and Wiltschko 2003). More recently, landmarks, individuality map, sun compass, olfactory cues and, in particular, the geomagnetic field effects in pigeon homing of the last 40 years were reanalysed, suggesting that pigeons use multiple and redundant cues to find their way home (Walcott 2005). Similarly, odour (Chaffiol et al. 2005), visual (Warrant et al.

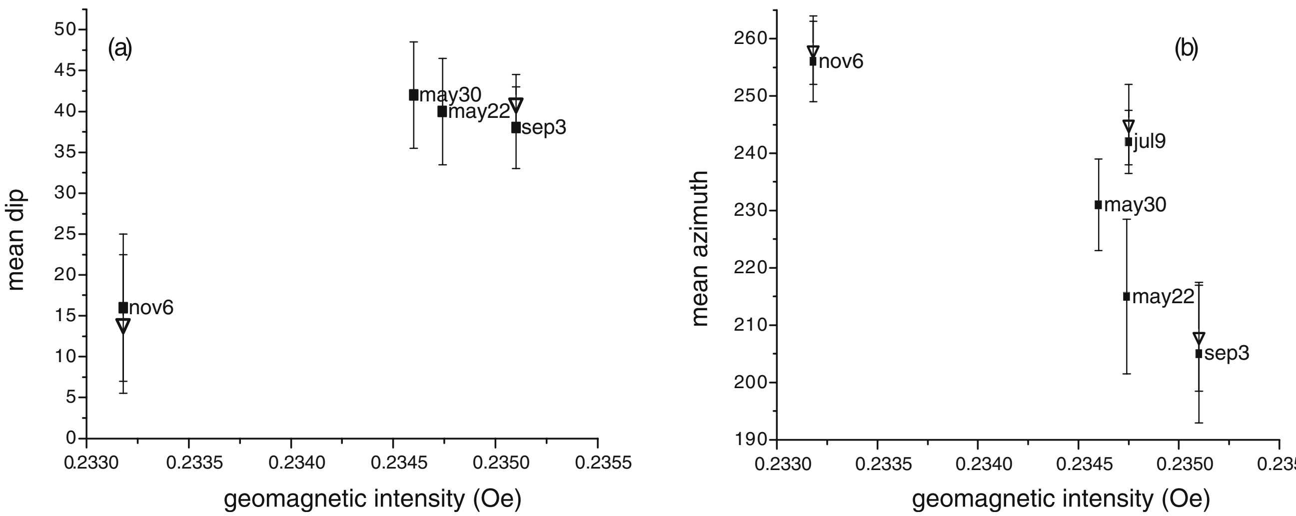

Fig. 2 Mean dip (**a**) and azimuth (**b**) angles as a function of geomagnetic intensity; geomagnetic field (control, *filled square*), applied magnetic field (*inverted open triangle*)

2004) and magnetic field (Gould 2004) cues provide bees with orientational references so that the multiple cues could be suggested for this insects, as already observed for intermodal blocking in foraging bees (Couvillon et al. 2001).

The fortunate event of a strong magnetic storm on the last experiment day allowed the first observation of magnetic behavioural change in *S. quadripunctata* bees, on bee flight orientation, in contrast with effects on *A. mellifera* comb building or dancing. Moreover, the experiments were performed in a region in the SAA, where characteristics are interesting for this study. *S. quadripunctata* is a new tribe for magnetoreception studies, especially for its close relationship to *A. mellifera* honeybees. The magnetic sensitivity, together with a magnetic sensor candidate (Lucano et al. 2006), should stimulate more controlled behavioural and neuroethological experiments with this species.

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We declare that the experiments comply with the current laws of Brazil.

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