

Short communication

Magnetic cues: are they important in Black-browed Albatross *Diomedea melanophris* orientation?

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Procellariiformes are well known for their excellent homing abilities (see references in Matthews 1968 and Dall'Antonia *et al.* 1995, Warham 1996). Albatrosses, in particular, have a reputation as skilful oceanic navigators since they can cover enormous distances during foraging flights and pinpoint a specific remote island where their colonies are located. A crucial experiment carried out on Laysan Albatrosses *Diomedea immutabilis* (Kenyon & Rice 1958) showed that these birds managed to home to their colony after a passive displacement of 2116–6629 km in the Pacific Ocean. The masterly navigation abilities of albatrosses clearly involve a high-precision navigation system. Many studies have previously described the biology of different species, but, to our knowledge, only a few have focused on the mechanism used to achieve such extraordinary performances. The two main hypotheses proposed are egocentric navigation principles (path integration) as in hymenopterans, and true navigation (see Papi 1992 for references). True navigation postulates the existence of a map (large-scale bi-coordinate maps) and compass (solar, magnetic) mechanism (Wallraff 1990).

Evidence obtained from other birds suggests that sensitivity to the earth's magnetic field might be involved in the orientation mechanisms of albatrosses. Several species of migratory passerine birds use a magnetic compass during the migratory trip while homing pigeons are reported to be disorientated if carrying magnets or in sites where magnetic anomalies exist (see Wiltschko & Wiltschko 1996). Magnetic fields could be important for sea turtles also. Like albatrosses, sea turtles are excellent oceanic navigators, and move in a uniform environment where the lack of landmarks eliminates their implicit capacity to guide animals (Carr 1984, Papi & Luschi 1996). Hatchling Loggerhead Sea Turtles *Caretta caretta* can detect two geomagnetic parameters: the angle of inclination and the total field intensity (Lohmann & Lohmann 1994, 1996a, 1996b,

1998). These two parameters, varying along gradients across the earth's surface, would provide turtles with a bi-coordinate map useful to determine their position relative to a goal area. However, the only attempt to test the geomagnetic navigation hypothesis in migrating adult Green Turtles *Chelonia mydas* failed (Papi *et al.* 2000). A geomagnetic bi-coordinate mechanism has been proposed for birds but never demonstrated (Wiltschko & Wiltschko 1996). Considering this possibility Åkesson and Alerstam (1998) have recently investigated whether any combination of different geomagnetic parameters forms a reliable bi-coordinate map suitable for Wandering Albatrosses *Diomedea exulans* to navigate at sea. Their findings indicate that, in some areas, the use of a magnetic gradient map could not be possible although they do not exclude the existence of such a system used elsewhere.

The first step to investigating whether this parameter has a role in albatross orientation is to interfere with the bird's perception of the Earth's geomagnetic field. The simplest way to achieve this is to perform homing experiments with birds equipped with magnets that alter the animal's perception of the magnetic fields around it (e.g. Keeton 1971, Wallraff & Foà 1982, Ioalé 1984, Moore 1988, in homing pigeons and Massa *et al.* 1991 in *Calonectris diomedea*). If magnetic field is important in albatross orientation, a bird deprived of the correct perception could perform poorly during foraging trips. We report the results of an experiment in which we recorded the foraging performance of Black-browed Albatrosses *Diomedea melanophris* carrying magnets.

METHODS

The experiment took place in November 1999, during the Black-browed Albatross incubation period on the Kerguelen Islands, southern Indian Ocean. The weather conditions in this area are normally overcast with just a few, sporadic sunny days. The colony is located at Cañon des Sourcils Noirs (49°41'S, 70°14'E), Jeanne d'Arc Peninsula, south-east of the main land mass. Incubating birds alternate at the nest with shifts lasting 1–8 days, average 4 days (Weimerskirch unpubl. data, Weimerskirch *et al.* 1988).

Several nests were selected in an accessible part of the colony and one adult of each pair was marked on the breast with a patch of picric acid to facilitate identification at a distance. Both experimental ($n = 7$) and control ($n = 5$) birds were captured after they had been relieved by their partner, just before leaving for a foraging trip. Each individual was weighed and equipped with magnets or dummies. Immediately afterwards the birds were released in the proximity of their nest and observed to record the departure time. On returning from a foraging trip the birds were weighed and the experimental equipment was removed. During the study period, another part of the colony 100 m from this experimental area was selected to measure the duration of foraging trips of 11 albatrosses

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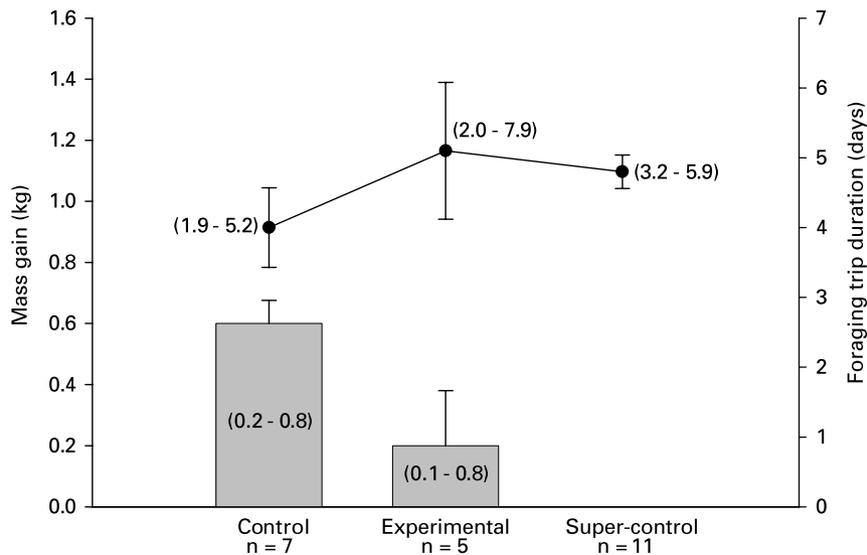


Figure 1. Mean mass-gain (columns) and foraging trip duration (line) of birds of the three treatments. Bars refer to se; range is given in parentheses.

that were not handled (super-control birds). The nests of these birds, as well as those of manipulated birds, were observed from dawn to dusk, from a vantage point, to record the arrival and departure times.

Experimental birds were equipped with neodymium magnets (type Neo 35, Calamit Trading, Milan, Italy; nominal neodymium residual induction: 1.17–1.22 T) on the head and wings. The cylindrical neodymium magnet on the head (diameter 4 mm, length 20 mm) was contained in a U-shaped PVC container (42 mm × 16 mm, thickness of PVC 1 mm; total weight of container plus magnet 6 g) in which it was free to move. This method caused a non-static magnetic disturbance around the head of the bird and prevented magnetoreception based on induction (Wiltschko & Wiltschko 1995). The container was attached by cyanoacrylate glue on the head feathers. Since nothing is known about the actual position of a possible magnetoreceptor, a cylindrical neodymium magnet (diameter 3 mm, length 27 mm) was attached with adhesive tape on the upper part of each wing, between the body and the forearm, to disrupt magnetic perception around the whole animal. In this case the natural movements of the wings caused a non-static magnetic disturbance. Both types of magnets still produce a magnetic field at 20 cm distance similar to the geomagnetic field intensity (total field intensity in the Kerguelen sector, approximately 48 000 nT). In control birds, magnets were replaced with brass bars of the same shape and dimensions as the magnets.

RESULTS

After the foraging trip all the birds equipped with magnets returned with their experimental equipment intact,

whereas one control bird had lost the dummy on the right wing and two control birds had lost the container on the head. Foraging trip duration was similar for the three groups of birds (Fig. 1; Mann–Whitney *U*-test: super-control/control group, $U = 21.5$, $N_1 = 11$, $N_2 = 5$, ns; control/experimental group $U = 13$, $N_1 = 5$, $N_2 = 7$, ns; super-control/experimental group $U = 41$, $N_1 = 11$, $N_2 = 7$, ns). Mass-gain (Fig. 1) was similar in the experimental and control groups (Mann–Whitney *U*-test $U = 23$, $N_1 = 5$, $N_2 = 7$, ns).

DISCUSSION

Black-browed Albatrosses forage at hundreds of kilometres from their nests during the breeding season (Prince *et al.* 1997, Weimerskirch *et al.* 1997) and during the non-breeding period they disperse at sea, thousands of kilometres from their colonies (Weimerskirch *et al.* 1985). These capacities imply high-precision navigation systems. Our experiment showed that the application of permanent magnets to the wings and head produced no significant disturbance of the behaviour of Black-browed Albatrosses during their foraging trips. Trip duration of experimental birds did not differ from those of control and super-control birds and their foraging success was similar to that of control birds. Although we cannot exclude the possibility that, because of the relatively small samples, small effects might have been missed (Type II error), this result suggests that magnetic cues are not critical for albatrosses during foraging trips. During the experiment, Black-browed Albatrosses from the study colony were foraging at an average distance of 300 km from the nest (mean trip duration 7 days, H. Weimerskirch unpubl. data) in similar areas to

those exploited during the chick-rearing period (Weimerskirch *et al.* 1997). This distance prevented birds from seeing land directly and thus birds could not be guided by familiar terrestrial topographic cues.

Although adult sea turtles seem to disregard magnetic information for orientation (Papi *et al.* 2000), hatchlings have been shown to detect small differences in two values of the geomagnetic field that could be used in a bi-coordinate map (Lohmann & Lohmann 1994, 1996a, 1996b, 1998). In contrast, the compass sense of passerine birds is based on the angle of inclination (see Wiltschko & Wiltschko 1996 for references). Consequently, a map and compass mechanism based on magnetic cues could be a reliable system. The application of permanent magnets on the head and body of a bird produced a generic disturbance to the perception of the magnetic field. Thus, we cannot say whether we disrupted any magnetic compass or magnetic map or both. Åkesson and Alerstam (1998) showed that, around the Crozet Islands, it is not possible to form a reliable bi-coordinate magnetic map that albatrosses might use for orientation. They also provided isomagnetic maps that showed that the magnetic situation around the Kerguelen Islands is similar to that around the Crozet Islands. Thus it should be impossible to use a bi-coordinate map formed just by magnetic gradient fields here also. Taking this into account, we can assume that we interfered mainly with a possible magnetic compass even if we cannot exclude a type of bi-coordinate map in which geomagnetic field plays an important role for at least one of the two coordinates.

A possible explanation of our results is that the albatrosses might use different systems of navigation according to the availability and reliability of cues. Many animals use redundant mechanisms to orientate, and some cues would become more or less important depending on the environmental context (see Papi 1992 for references). For example, homing pigeons are assumed to rely on a time-compensated sun compass to maintain a correct homeward route, whereas a time-independent magnetic compass is supposedly used in overcast conditions (Holland *et al.* 2000, references in Wiltschko & Wiltschko 1996). However, if albatrosses relied mainly on magnetic cues we should see reduced performance in experimental birds. Birds would be disorientated initially and only later, when they realized that the system used was wrong, they could shift to another orientation mechanism. In the same way, clock-shifted homing pigeons show initial deflections from the home direction. Once corrected, the birds return to their loft with reduced homing performances (Papi *et al.* 1991, Bonadonna *et al.* 2000).

Another possibility is that albatrosses, at least during relatively short foraging trips in the Kerguelen area, do not use geomagnetic cues. Nevitt (1999) has shown that Black-browed Albatrosses respond to food-related odour cues, suggesting that olfaction probably plays an important role in locating feeding zones at sea. Moreover, some

authors have reported that olfaction is important in finding colonies and burrows in burrowing petrels (Grubb 1973, 1974, Benvenuti *et al.* 1993, Minguez 1997, Bonadonna *et al.* 2001). Hence, an odour landscape composed of oceanic odours and specific odours from the islands might be important for albatross navigation during relatively short foraging flights (Bonadonna 2001).

In conclusion, we cannot exclude the possibility that albatrosses could use magnetic cues to return to their colonies but geomagnetic navigation does not seem to be critical, at least during foraging activity. However, since in our experiments we did not record foraging trip tracks, further experiments are necessary to identify less pronounced effects that are not detectable through recording just the foraging trip duration and state of arrival back at the colony.

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