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## Comment on “Quantum Coherence and Sensitivity of Avian Magnetoreception”

Several papers [1–3] have studied the quantum physics of the radical pair mechanism hypothesized to underlie the avian compass. Our 2011 Letter [2] analyzed the coherence time of the electron spin pair and found that it must be surprisingly long. To be consistent with behavioral studies on European Robins involving weak radio frequency (rf) fields [4,5], the coherence time should be of order 100  $\mu$ s or more. Interestingly, this is considerably longer than the reported 6  $\mu$ s radical pair lifetime from *in vitro* experiments on cryptochrome [6], widely considered a potential candidate for the avian compass [7].

Utilizing the radical pair model we described in Ref. [2], Bandyopadhyay *et al.* seek to close this gap by considering additional behavioral studies, as reported in a very recent Letter [8]. However, their analysis suffers from two errors: an erroneous numerical computation together with the omission of vital experimental data. These issues are multiplicative and result in an underestimate of the lower bound by a factor of about 40. Consequently, the estimate of the lifetime given in the paper as 5–6.7  $\mu$ s, and described as “of the order of a microsecond” in their abstract, in fact becomes 200–270  $\mu$ s, i.e., hundreds of microseconds.

To test the validity of Bandyopadhyay-Paterek-Kaszlikowski’s (BPK) numerical calculation, we regenerated their simulation results using exactly the model and the parameters which they select. After an exhaustive series of simulations, we conclude that it is not possible to reproduce the graphs in BPK’s Letter. One can match the line shapes exactly, but to do so one must rescale by a factor of four either the time axis or the spins’ g-factors. In an online document [9], we provide complete details of our analysis for scrutiny. Furthermore, we have been made aware that an independent researcher also found it impossible to reproduce BPK’s results without artificially scaling the model parameters [10]. Evidently, there is an error in the numerical code employed by BPK.

In deriving lifetime estimates, both our original Letter and BKP’s vitally depend on the effect of weak resonant fields in disrupting the birds’ compass sense. Experimentalists have reported disruptions for fields of strength 470 nT to 15 nT. In our paper we took the value of 150 nT to ensure a conservative estimate; however, to argue that a specific shorter process timescale is consistent with the body of behavioral experiments, the analysis should be based on the weakest rf field known to disrupt the bird’s compass sense, i.e., 15 nT. BPK perform their calculations for  $B_{\text{rf}} = 470, 150,$  and 47 nT, but inexplicably they omit the crucial 15 nT datum (see Fig. 3 of Ref. [5], which BPK cite as their Ref. [13]). The effect of including this result is to increase the lower bound on the lifetime by a factor of about 10, which becomes 40

in view of the numerical error described above [9]. Stated alternatively: the timescale reported by BKP is not consistent with the reported disruption of the avian compass at fields of 15 nT; any bird whose compass lifetime is confined to microseconds (or indeed 10s of microseconds) must be immune to a 15 nT oscillatory field.

BKP’s observation that long coherence is not required for a compass sense remains correct. However, this is not a novel observation, having been stated and analyzed in our 2011 Letter [2] and in Ref. [3]; the latter specifically examined the cases where noise is beneficial. Notwithstanding the puzzle of why the bird should evolve an unnecessarily long lifetime [11], the available data [4,5,12] applied to a proper quantum mechanical model of the radical pair mechanism nevertheless indeed imply that the life- and coherence time is of order 100  $\mu$ s or more.

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