Author's Accepted Manuscript

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PII: S0022-5193(16)30244-2
DOI: http://dx.doi.org/10.1016/j.jtbi.2016.08.010
Reference: YJTBI8778

To appear in: *Journal of Theoretical Biology*

Received date: 16 December 2015
Revised date: 5 August 2016
Accepted date: 10 August 2016

Cite this article as: Brian K. Taylor, Validating a model for detecting magnetic field intensity using dynamic neural fields, *Journal of Theoretical Biolog* http://dx.doi.org/10.1016/j.jtbi.2016.08.010

Validating a model for detecting magnetic field intensity using dynamic neural fields

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Abstract

Several animals use properties of Earth's magnetic field as a part of their navigation toolkit to accomplish tasks ranging from local homing to continental migration. Studying these behaviors has led to the postulation of both a magnetite-based sense, and a chemically based radical-pair mechanism. Several researchers have proposed models aimed at both understanding these mechanisms, and offering insights into future physiological experiments. The present work mathematically implements a previously developed conceptual model for sensing and processing magnetite-based magnetosensory feedback by using dynamic neural fields, a computational neuroscience tool for modeling nervous system dynamics and processing. Results demonstrate the plausibility of the conceptual model's predictions. Specifically, a population of magnetoreceptors in which each individual can only sense directional information can encode magnetic intensity en masse. Multiple populations can encode both magnetic direction, and intensity, two parameters that several animals use in their navigational toolkits. This work can be expanded to test other magnetoreceptor models.

Keywords: magnetic reception magnetoreception magnetosensing dynamic neural field navigation alternative navigation

1. Introduction

Several animals use the Earth's magnetic field in concert with other sensing modes to accomplish tasks ranging from local homing to continental migration (e.g., Johnsen and Lohmann (2005, 2008), the special edition on magnetosensing by the Journal of the Royal Society: Interface (2010), Wiltschko and Wiltschko (1995)). Earth's magnetic field is a three-dimensional vector field that extends from Earth's surface up through the atmosphere. It is typically described by its intensity (i.e., vector magnitude), inclination angle (i.e., angle between the vector and the local horizontal plane), and the declination (i.e., difference between magnetic and geographic north) (Knecht and Shuman, 1985; Wajnberg et al, 2010). An illustration of Earth's magnetic field is shown in Fig. 1A.

A number of behavioral and physiological experiments suggest that several animals use magnetic intensity as part of their navigation toolkit (Lohmann et al., 1999; Putman et al, 2011; Wiltschko and Wiltschko, 2013). Magnetic materials such as magnetite appear to be viable candidates that may explain how an intensity sense could work. Some studies have obtained and/or cataloged evidence to support how this mechanism may work at the neural and cellular levels (Wiltschko and Wiltschko (2013); Shaw et al. (2015); Vidal-Gadea et al (2015); Wu and Dickman (2012); Eder et al. (2012)). However, the mechanism has not been directly observed or fully explained. While several researchers have taken steps that may provide direct observations of this elusive phenomenon (e.g., Vidal-Gadea et al (2015); Eder et al. (2012)), the issue is still active and open for discussion (Edelman et al., 2015).

Based on previous studies (Kirschvink et al, 1992; Kirschvink and Walker, 1985; Kirschvink and Gould, 1981), Walker (2008) proposed a conceptual mechanism for how a magnetite-based receptor might encode magnetic intensity based on distributed detection