Review Article
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Magnetic alignment behavior in cattle: a review of biological foundations and the potential disruptive effects of electromagnetic fields

Abstract

The Earth's natural magnetic field is a constant environmental factor in which living organisms exist without being consciously aware of it. It has long been known that some animals are able to use this field for orientation or for adjusting their body position. In recent years, field-based studies have revealed a notable behavioral pattern in cattle. Grazing or resting cattle have been reported to align their body axis predominantly along the north–south direction. This behavior is defined as magnetic alignment.

Magnetic alignment is not a conscious orientation behavior. It is considered an automatic and passive behavioral response associated with body posture and resting position. In this review, the existing literature on magnetic alignment behavior in cattle is evaluated within a simple and integrative framework. Proposed biological mechanisms underlying magnetic field perception in animals are summarized, and their possible relevance to cattle is discussed.

In modern livestock systems, animals are exposed not only to the Earth's natural magnetic field but also to artificial electromagnetic fields. Therefore, the potential disruptive effects of electromagnetic fields on magnetic alignment behavior are examined based on available literature. Current studies do not provide conclusive evidence that electromagnetic fields directly disrupt magnetic alignment. However, some observational findings suggest that this behavior may be sensitive to disturbances in the integrity of the surrounding magnetic environment.

In conclusion, magnetic alignment in cattle is a real phenomenon supported by consistent field observations. Nevertheless, the biological basis of this behavior and its relationship with electromagnetic environments have not yet been fully clarified. This indicates that magnetic alignment represents a promising area for future field-based research in terms of animal behavior and animal welfare.

Keywords: cattle, magnetic alignment, magnetoreception, electromagnetic fields, animal behavior, animal welfare

Volume 11 Issue 1 - 2026

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Received: January 19, 2026 | **Published:** January 30, 2026

Introduction

The Earth is surrounded by a natural magnetic field in which living organisms exist without being consciously aware of it. This field enables the functioning of compasses and originates from the Earth's core. Living organisms cannot see or directly perceive this field. However, it has long been known that some animals are able to use the Earth's magnetic field for orientation or for adjusting their body position.[1,2]

Magnetic field–related behaviors in animals were first described in birds. The ability of migratory birds to orient correctly even in darkness represents one of the strongest indications of magnetic field perception.[3] Subsequent studies have demonstrated similar orientation behaviors in fish and in some mammals.[4,5] These findings suggest that magnetic field perception is not a trait limited solely to migratory behavior.

In recent years, field studies have revealed a remarkable behavioral pattern in large mammals. Free-ranging or resting cattle and deer have been reported to frequently align their bodies along the north–south axis.[6] This behavior is defined as *magnetic alignment*. Magnetic alignment does not represent a conscious directional choice by the animal; rather, it is considered an automatic and unintentional postural pattern.[5,7]

In modern livestock production systems, animals are exposed not only to the natural geomagnetic field but also to artificial electromagnetic fields. Electrical panels, motors, milking systems, ventilation fans, and power lines generate low-frequency magnetic fields within animal housing facilities. Although these fields are generally of low intensity, animals spend a substantial portion of their daily lives in such environments.[8,9]

In the literature, the effects of electromagnetic fields on cattle health, productivity, and behavior have mainly been examined through hormonal responses, milk yield, and physiological indicators.[10,11] In contrast, the relationship between magnetic alignment behavior and the electromagnetic environment has been investigated in only a limited number of studies. In particular, it remains insufficiently clarified whether natural magnetic alignment in cattle can be disrupted by artificial electromagnetic fields.[7,12]

The aim of this review is to present current knowledge on magnetic alignment behavior in cattle within a clear and accessible framework, to describe the biological foundations of this behavior, and to evaluate the potential disruptive effects of electromagnetic fields in light of the existing literature.

Magnetic field perception in animals

The ability of animals to exhibit behaviors related to the magnetic field is explained by the concept of magnetoreception, which has been widely described across different animal groups. Magnetoreception refers to an animal's ability to perceive information related to the direction or intensity of the Earth's magnetic field through its body.[2,13] This perception does not constitute a conscious sensory modality such as vision or hearing. In most cases, animals use this information unconsciously.[3]

With regard to how magnetoreception occurs in animals, three main explanatory mechanisms are described in the literature. These explanations are based on studies conducted in different animal species.[11,13] However, there is no definitive evidence demonstrating that these mechanisms operate directly in cattle. Nevertheless, the regular magnetic alignment behavior observed in cattle suggests that these mechanisms may contribute to understanding magnetoreception in this species.[6,12]

Magnetite-based perception

It has been reported that some animals possess very small iron oxide crystals with magnetic properties in their body tissues. These crystals are referred to as magnetite. Magnetite is thought to physically respond to the Earth's magnetic field and to undergo microscopic movements when the direction of the field changes. It has been proposed that these movements may stimulate nerve endings and transmit directional information to the brain.[2,13]

The presence of magnetite has been demonstrated through anatomical and experimental studies in birds and some fish species. Similar structures have also been reported in small mammals.[13] In cattle, however, there is no direct evidence for the presence of magnetite crystals. Despite this, the regular magnetic alignment behavior observed in cattle suggests that a magnetite-based perception system may indirectly exist in this species.[6,7]

Cryptochrome-based mechanism

The second mechanism has been primarily identified through studies conducted in birds. Cryptochromes, which are light-sensitive proteins located in the eye, are suggested to interact with the magnetic field. According to this mechanism, the animal does not directly "sense" the magnetic field; instead, the magnetic field induces subtle changes in visual perception, thereby providing indirect directional information.[3,11]

Cryptochrome-based magnetoreception has been strongly supported in birds. However, in mammals, particularly in cattle, there is no conclusive evidence demonstrating that cryptochromes play an active role in magnetic field perception.[2] Moreover, the observation that magnetic alignment behavior in cattle also occurs under nighttime conditions suggests that a light-dependent mechanism alone may not be sufficient to explain this behavior.[6]

Vestibular system

The third approach proposes that magnetoreception may be associated with the vestibular system, which controls balance and posture. The vestibular system is one of the primary sensory systems responsible for regulating body position, head orientation, and postural stability. According to this hypothesis, magnetic field–related signals may contribute to a more stable or comfortable body orientation in a particular direction.[11]

This explanation is considered particularly relevant for animals with large and heavy body structures. Cattle spend a substantial portion of the day either standing or lying down. Postural comfort and balance are regarded as important aspects of animal welfare.[10] In this context, magnetic alignment behavior is interpreted not as a conscious directional choice but rather as an automatic adjustment associated with bodily comfort.[7]

In summary, the biological basis of magnetoreception is explained by different mechanisms across animal groups. In cattle, however, it remains unclear which of these mechanisms may be operative. Nevertheless, the consistent observation of magnetic alignment behavior across multiple studies suggests that this behavior is likely based on a biological foundation.[6,12] In some studies conducted on mammals, differences in posture and orientation behavior have been observed in response to small-scale variations in the Earth's magnetic field. These findings indicate that magnetoreception in mammals may represent a behavioral component that is sensitive to environmental conditions.[14]

Magnetic alignment behavior in animals

Magnetic alignment behavior in animals has been demonstrated through observational and experimental studies conducted across different species. This behavior is defined as the positioning of the animal's body along a specific axis relative to the Earth's magnetic field during resting, grazing, or periods of immobility. In most studies, this axis has been reported to correspond to the north–south direction.[6]

Magnetic alignment differs from navigational behavior. The animal does not move toward a specific target nor does it consciously choose a direction. Instead, it aligns its body along a particular axis while standing or lying. For this reason, the behavior is considered reflex-like and automatic in nature.[5]

Magnetic alignment in birds

The strongest and earliest evidence for magnetic field perception has been obtained from studies on birds. Foundational research in this field has focused primarily on migratory bird species. In the classical experiments conducted by Wiltschko and Wiltschko, birds were placed in completely dark environments, eliminating the sun, stars, and visual directional cues. Under these conditions, the magnetic field within the experimental setup was artificially rotated to different orientations.[1,3]

When the direction of the magnetic field was altered, a corresponding shift in the preferred orientation of the birds was clearly observed. For example, birds that oriented northward under normal conditions were reported to orient eastward when the magnetic field was rotated by 90 degrees. These results demonstrated that birds do not treat the magnetic field as a passive environmental factor but actively use it as a source of directional information.[3]

Subsequent studies investigated the biological basis of magnetoreception in birds. The presence of magnetite crystals with magnetic properties has been demonstrated in the beak region and around the brain, and these structures were reported to be connected to neural tissue.[13] In addition, experiments in which these regions were temporarily disabled showed a disruption of orientation ability in birds. These findings strongly support the existence of a biological basis for magnetoreception in birds.

Magnetic alignment in fish

Magnetic alignment and orientation behavior in fish have been studied primarily in species that perform long-distance migrations. In studies conducted on species such as salmon and eels, fish were placed in controlled tank environments, and the direction of the magnetic field was artificially manipulated (Quinn, 1980).[4] In these experiments, environmental factors such as light, water currents, and olfactory cues were kept constant.

When the direction of the magnetic field was changed, fish were shown to alter their swimming direction accordingly. This response was reported to be particularly pronounced in juvenile individuals. Some studies have suggested that fish may use the magnetic field not only for directional orientation but also to obtain coarse information about their geographic position.[15]

The limited availability of visual cues in underwater environments suggests that magnetoreception represents an important source of environmental information for fish. These findings indicate that magnetic alignment is not restricted to terrestrial animals and may represent an evolutionarily ancient trait.[4]

Magnetic alignment in small mammals

Experimental studies on magnetic alignment in mammals have been conducted mainly on small mammal species. Mole rats, hamsters, and laboratory mice are among the most frequently studied species in this field. In these studies, nesting and resting behaviors have commonly been used as behavioral indicators.[7,16]

Experiments on mole rats have shown that animals construct their nests along specific orientations rather than randomly. When the magnetic field in the experimental environment was rotated by 90 or 180 degrees using Helmholtz coils, the orientation of the nests shifted by the same angle.[16] This result indicates that the behavior is based on the direct use of magnetic field information rather than environmental learning.

Similar studies conducted on hamsters and laboratory mice have demonstrated that resting position and nest orientation are associated with the magnetic field. In some experiments, animals were tested with their eyes covered or under complete darkness, yet alignment behavior persisted.[12] This finding supports the conclusion that the behavior is not dependent on visual cues.

A common feature of these studies is that experimental manipulation of the magnetic field resulted in corresponding changes in behavior. This consistency strongly indicates that magnetic alignment in small mammals is a biologically based trait.

Table 1 summarizes the methods used to investigate magnetic alignment behavior across different animal groups and the strength of the available evidence. In birds and fish, direct changes in behavior following experimental manipulation of the magnetic field indicate a high level of causal evidence. In small mammals, behavioral evidence is strong; however, findings obtained in large mammals are predominantly based on field observations.

Table 1 Key studies on magnetic alignment behavior across different animal species

Species	Research approach	Method	Findings
Migratory passerine birds	Controlled laboratory experiments	Artificial rotation of the magnetic field under dark conditions	Alteration of the magnetic field direction resulted in a corresponding shift in preferred orientation
Salmon, eels	Controlled tank experiments	Manipulation of magnetic field direction while environmental cues were kept constant	Swimming direction adjusted in accordance with the magnetic field orientation
Mole rats, hamsters, laboratory mice	Semi-controlled experiments	Rotation of the magnetic field using Helmholtz coils; analysis of nest orientation	Nesting and resting orientation changed consistently with the magnetic field direction
Cattle, deer	Large-scale field observations	Satellite imagery, field observations, and statistical orientation analyses	Body axis aligned predominantly along the north–south direction during resting and grazing

Magnetic alignment behavior in cattle

Magnetic alignment behavior in cattle has been documented through large-scale field observations rather than controlled laboratory experiments, as is the case for birds and small mammals. Due to experimental constraints associated with large-bodied animals, investigations of magnetic alignment in cattle have relied primarily on observations conducted in natural settings.[5,6]

This behavior was first identified through systematic analyses of satellite images of free-ranging and resting cattle herds. Using high-resolution satellite photographs of herds located in different geographic regions, assessments demonstrated that cattle positioned their body axes not randomly but predominantly along the north–south direction.[6]

Similar observations of magnetic alignment in large mammals have been reported in species other than cattle, such as deer. This finding suggests that the behavior is not a species-specific coincidence but may reflect a shared biological basis among mammals.[6,7]

The consistent observation of magnetic alignment behavior in cattle across different climates, pasture types, and herd sizes indicates that environmental factors alone are insufficient to explain this phenomenon. When variables such as terrain slope, wind direction, and solar position were statistically evaluated, they were reported to be unable to account for the alignment behavior to a significant extent.[6,11]

The behavior is most pronounced during resting and grazing. When animals are moving or actively changing direction, no clear orientation pattern is observed. This suggests that magnetic alignment

Citation: Bingöl S, Göncü S. Magnetic alignment behavior in cattle: a review of biological foundations and the potential disruptive effects of electromagnetic fields. *MOJ Eco Environ Sci.* 2026;11(1):13–17. DOI: 10.15406/mojes.2026.11.00374

represents a passive behavioral pattern associated with posture and lying position rather than a navigational behavior.[7] In contrast, some studies employing experimental setups have reported no clear north–south orientation pattern in cattle, emphasizing that magnetic alignment behavior may vary depending on environmental conditions and observation methods (Weijers et al., 2018).

In some studies, regular alignment behavior has been reported to weaken or disappear in areas where the structure of the natural magnetic field is disrupted. In particular, observations have shown that the body orientation of large mammals becomes more irregular in areas near high-voltage power lines.[7,12] These findings suggest that magnetic alignment behavior may be sensitive to the integrity of the surrounding magnetic environment.

Nevertheless, there are currently no controlled experimental studies demonstrating that electromagnetic fields directly disrupt magnetic alignment in cattle. Available evidence is largely observational in nature, and the causal relationship remains unclear.[11]

In summary, magnetic alignment behavior in cattle represents a phenomenon supported by strong field-based evidence. However, the biological mechanisms underlying this behavior and its sensitivity to environmental electromagnetic fields have not yet been fully elucidated. This indicates that magnetic alignment in cattle remains an open research area with relevance to behavioral science and animal welfare.

Disruptive effects on magnetic alignment behavior

The Earth's natural magnetic field is large-scale, stable, and continuous. In contrast, electromagnetic fields generated by human activities are typically local, irregular, and temporally variable. This fundamental difference between natural and artificial magnetic fields may influence how animals perceive and utilize magnetic field information.[11,13]

For magnetic alignment behavior to occur, the directional information of the magnetic field within the animal's environment must remain stable. The literature reports that when the magnetic field is spatially disturbed or when directional information becomes inconsistent, behaviors based on magnetic perception may weaken. This phenomenon is commonly described by the concept of a *disruptive effect*, particularly in environments where artificial electromagnetic fields overlap with the natural geomagnetic field.[3,11]

Some field studies conducted in cattle have reported that magnetic alignment behavior may become more irregular in areas near high-voltage power lines. Evidence from field studies on ruminants further supports the notion that magnetic alignment behavior may be sensitive to the integrity of the surrounding magnetic environment. Observations in areas with high-voltage power lines have shown that the body orientation of cattle and deer deviates significantly from the north–south direction. These findings suggest that low-frequency electromagnetic fields may weaken magnetic alignment behavior by disrupting the natural geomagnetic field structure.[5]

Begall et al.[7] reported that in regions where the structure of the natural magnetic field is disturbed, cattle exhibit deviations from the north–south axis and display a more random distribution of body orientation. This finding further supports the interpretation that magnetic alignment is a behavior sensitive to the integrity of the environmental magnetic field.

Similar disruptive effects have also been demonstrated in experimental studies conducted on birds and small mammals. Small-scale and irregular alterations in magnetic field direction have led to instability and inconsistency in orientation behavior.[12,17] These studies indicate that magnetic perception depends not only on field intensity but also on the directional coherence of the magnetic field.

In livestock production systems, electromagnetic fields are most commonly concentrated around electrical panels, motors, milking systems, and power transmission lines. It has been reported that these fields are not homogeneously distributed within animal housing facilities and may create localized magnetic irregularities.[9,18] Such irregularities have the potential to disrupt the continuity of the magnetic environment perceived by animals.

However, the current literature does not include controlled experimental studies demonstrating that electromagnetic fields directly disrupt magnetic alignment in cattle. Available findings are largely observational, and therefore the causal relationship between electromagnetic fields and magnetic alignment remains unclear.[11]

In summary, the literature suggests that electromagnetic fields may exert disruptive effects on magnetic alignment behavior. Nevertheless, this effect is primarily supported by behavior-based observations and has not yet been clarified at the mechanistic level. This highlights the need for controlled field studies and behavior-based assessments in future research.

Magnetic alignment behavior and animal welfare

Animal behavior is considered one of the earliest and most reliable indicators for assessing welfare status. An animal's posture, lying position, orientation, and spatial relationship with its environment can provide information about welfare conditions before physiological changes become apparent.[19,20] Therefore, subtle and less conspicuous behavioral patterns such as magnetic alignment may be meaningful in the context of welfare assessment.

Magnetic alignment behavior is defined as an automatic response of the animal to environmental magnetic information. The regular occurrence of this behavior suggests that the animal's environmental perception systems are functioning properly. In contrast, in environments where magnetic field information is disrupted or becomes complex, this behavior may weaken or disappear.[6,12]

The literature does not provide a definitive classification of magnetic alignment as a direct indicator of animal welfare. However, some researchers have reported that environmental stressors can influence animals' orientation and postural behaviors.[8,21] In this context, irregularities in magnetic alignment behavior have been proposed to reflect a reduced capacity for environmental adaptation.

In cattle, welfare assessments are commonly based on indicators such as lying time, rumination behavior, postural changes, and avoidance responses. These behaviors are known to be sensitive to environmental stress factors.[10] Magnetic alignment may similarly be considered a behavior responsive to environmental conditions. However, further evidence is required before it can be used as a welfare indicator. A recent study reported that deviations of stall orientation from the north–south direction in dairy cattle were associated with housing-related injuries and certain skin lesions. This finding suggests that posture and lying orientation may be indirectly related to animal welfare (Povše et al., 2024).

Some studies have reported that animals exposed to high levels of environmental stress exhibit more irregular posture and orientation. Factors such as noise, vibration, and housing irregularities are known to influence animals' lying and standing preferences.[22] Electromagnetic fields may similarly be considered factors that affect the integrity of the animal's environmental perception.[11]

For these reasons, magnetic alignment behavior is recommended to be evaluated not as a standalone criterion in welfare assessments but in combination with other behavior-based indicators. Subtle and quiet changes in animal behavior may provide valuable insights, particularly when assessing long-term environmental exposures.

In summary, the relationship between magnetic alignment behavior and animal welfare has not yet been fully clarified. Nevertheless, existing evidence suggests that this behavior may be associated with environmental perception and behavioral integration. This indicates that magnetic alignment could represent a parameter that may be integrated into behavior-based welfare assessments in the future.

Conclusion

Magnetic alignment behavior in cattle represents a genuine behavioral pattern documented through field studies conducted in different geographic regions. This behavior is observed as the tendency of animals to align their body axes predominantly along the north–south direction during resting and grazing. However, the biological basis and underlying mechanisms of this behavior have not yet been fully elucidated.

Current studies suggest that electromagnetic fields may exert a disruptive influence on magnetic alignment behavior. Nevertheless, controlled and behavior-based studies capable of establishing a causal relationship remain limited. Therefore, it is not possible to conclude definitively that electromagnetic fields directly disrupt magnetic alignment.

Magnetic alignment behavior is not considered a direct indicator of animal welfare. However, it is thought to be associated with the integrity of environmental perception and postural organization in animals. In this context, field-based studies that evaluate magnetic alignment together with behavioral observations, environmental measurements, and welfare indicators are expected to contribute to a better understanding of this phenomenon.

In conclusion, magnetic alignment behavior in cattle represents a noteworthy research area for understanding the relationship between behavioral science, environmental factors, and animal welfare. Simple, integrated, and field-oriented studies conducted in this area are likely to provide valuable insights for animal welfare and sustainable livestock production practices.

Acknowledgments

None.

Funding

None.

Conflicts of interest

The authors declare no competing interests.

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