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REVIEW

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The Role of Chemical Signals in Avian Communication: A Review

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Abstract

Avian species studied to date have a functioning sense of smell and use it for a variety of functions, including foraging and selection for mates. However, compared to other senses in birds, there has been relatively little research targeted towards olfaction, and it is far too often overlooked when designing experiments or interpreting experiments in which birds have been used as animals. The objective of this brief review is to provide a general review of our current state of knowledge about avian olfaction, and in this review, we are specifically focusing on articles on the chemical communication of birds. We are bringing to prominence studies, species, and topics potentially of greatest relevance to readers who are involved in research in animal behavior or cognition, and we finish by proposing some avenues for research in the future.

Keywords: Avian, Chemical communication, Behaviour, Olfaction

1. Introduction

Avian species can create different types of smell. The ancient literature indicated that birds not produced any types orders or little smell sense (Audubon, 1826; Hill, 1905; Stager, 1964). The studies conducted in the twentieth century provide significant proof about the necessary role of the olfactory sense in different anatomical and neurological functioning of birds (Balthazart & Taziaux, 2009; Caro, Balthazart, & Bonadonna, 2015).

2. Evidence for Avian Olfaction: Several studies have been conducted to provide evidence of avian chemical communication in different context

2.1. Neuroanatomical Studies: Birds possess highly advanced olfactory bulbs and genes for olfaction, as complex as in vertebrates and highly reliant on olfaction (Steiger et al., 2008) The complexity and size of these features are different in avian species, suggesting different capacities for olfaction appropriate for different ecological niches (Efford 2019).

2.2. Physiological Studies: Physiological processes and EOG recordings have confirmed that birds can perceive a host of different odours, including plant volatiles and chemical signals between members of the same species and food-associated odours (Nevitt 2000).

2.3. Behavioral Studies: A wealth of behavioral experiments has demonstrated that birds use olfaction in various contexts, including:

2.4. Foraging: Seabirds like albatrosses and petrels track olfactory cues for prey patches in the sea across extensive distances (Nevitt et al., 1995). Vultures track prey using their sense of smell, even in thick forest cover (Houston 1986). Insect-feeding birds can detect volatiles emitted by attacked trees and thus track prey indirectly (Amo & Saavedra 2021).

2.5. Navigation: Pigeons and other migratory birds use olfactory cues for homing and navigation, creating olfactory maps to orient themselves (Gagliardo 2013).

2.6. Social Behavior: Growing evidence suggests that birds use olfactory signals in social interactions, including species recognition, mate choice, and parent-offspring recognition (Bradbury& Vehrencamp 1998). Some studies showed that the olfactory abilities within different avian species in different context (Table-1)

Table 1: Examples of Bird Species and Their Olfactory Abilities

Bird Species	Olfactory Ability	Ecological Context	Reference
Albatrosses & Petrels	Locate prey patches using dimethyl sulfide (DMS)	Oceanic foraging	(Nevitt et al., 1995)
Vultures	Detect carrion odor (e.g., methyl mercaptan)	Scavenging	(Houston 1986)
Pigeons	Olfactory navigation and homing	Migration and homing	(Gagliardo 2013)
Domestic Chickens	Mate choice based on uropygial gland secretions	Reproduction	(Coria-Avila et al., 2005)
Zebra Finches	Discrimination of familiar vs. unfamiliar individuals based on Odor	Social recognition	Rossi et al., 2017)

3. Sources of Avian Chemical Signals

Birds produce a variety of chemical substances that can act as signals, originating from different sources throughout their bodies. These chemical signals can be broadly categorized based on their origin:

3.1. Uropygial Gland Secretions:

The uropygial gland, also known as the preen gland, is a bilobed gland located dorsally at the base of the tail. It is a prominent source of avian chemical signals, producing complex mixtures of waxes, fatty acids, and other compounds (Jacob & Ziswiler 1982). Birds spread these secretions onto their feathers during preening, a behavior crucial for plumage maintenance, waterproofing, and potentially, chemical communication (Roper 1999).

3.1.1. Chemical Composition: Uropygial gland secretions are chemically complex and species-specific, varying in composition based on sex, age, diet, and reproductive status (Martín-Vivaldi Martínez et al., 2017). Studies have identified various classes of compounds, including dialkyl esters, triacylglycerols, wax monoesters, and squalene (Praveenkumar et al., 2023).

3.1.2. Functions in Chemical Communication:

- **Mate Choice:** Differences in uropygial gland secretion composition between sexes and during breeding seasons suggest a role in mate attraction and mate choice (Sossinka 2011). For example, female domestic chickens seem to use male uropygial gland odors to assess mate quality (Coria-Avila et al., 2005).
- **Species Recognition:** Species-specific chemical profiles in uropygial gland secretions could contribute to species recognition, particularly in closely related sympatric species where visual and acoustic cues might be insufficient (McCubbin 2021).
- **Individual Recognition:** Subtle variations in uropygial gland secretions might allow for individual recognition within species, although this is less well-studied in birds compared to mammals (Jesseau 2004).

3.2. Feather-Derived Odors:

Feathers themselves can be a source of chemical signals, accumulating volatile compounds from uropygial gland secretions, diet, and the environment (Krause et al., 2023). These feather-derived odors can play a role in social signaling.

3.2.1. Chemical Composition: Feather odors are complex mixtures of volatile organic compounds (VOCs), including aldehydes, ketones, alcohols, and hydrocarbons (Alves Soares et al., 2021). The specific VOC profile can be influenced by factors like diet, preen gland secretions, and microbial communities on feathers (Shawkey et al., 2007).

3.2.1. Functions in Chemical Communication:

- **Sex and Species Recognition:** Plumage odors can differ between sexes and species, potentially contributing to sex and species recognition (Abankwah et al., 2020).
- **Signaling Individual Quality:** Feather VOC profiles might reflect individual quality, health status, or even genetic compatibility, providing information relevant to mate choice and social interactions (Whittaker et al., 2013).

3.3. Other Sources:

Besides uropygial gland secretions and feather odors, birds can produce chemical signals from other sources, although these are less extensively studied:

3.3.1. Feces: Bird feces contain volatile compounds that could potentially act as territorial markers or provide information about individual identity or health status (Roper & Jones 1997).

3.3.2. Stomach Oils: Procellariiform seabirds (e.g., petrels, albatrosses) produce stomach oils derived from their diet, which are highly odorous and used for defense, chick feeding, and potentially communication (Kuker 2008).

3.3.3. Salivary and Other Glands: Birds possess other glands, such as salivary glands and anal glands, which could potentially produce chemical signals, but their role in chemical communication remains largely unexplored (Johnston & delBarco-Trillo 2009). Several studies explored the functions of different chemicals in avian communication (Table-2)

Table 2: Sources of Avian Chemical Signals and Their Potential Functions

Source of Chemical Signal	Chemical Compounds	Potential Functions in Communication	Reference
Uropygial Gland	Waxes, fatty acids, esters, squalene	Mate choice, species recognition, individual recognition, plumage maintenance	(Jacob & Ziswiler 1982), (Sossinka 2011)
Feathers	Volatile organic compounds (VOCs), aldehydes, ketones	Sex recognition, species recognition, signaling individual quality	(Krause et al., 2023), (Abankwah et al., 2020)
Feces	Volatile compounds	Territorial marking, individual identity, health status	(Roper & Jones 1997).
Stomach Oils	Odorous oils derived from diet	Defense, chick feeding, potential communication	(Kuker 2008)

4. Role of Chemical Signals in Bird Behavior: A Multifaceted Communication Mode

Avian chemical signals play diverse roles in shaping bird behavior, influencing crucial aspects of their life history.

4.1. Reproduction:

Chemical signals are increasingly recognized as important mediators of avian reproductive behavior, influencing species recognition, mate choice, and potentially reproductive isolation.

4.1.1. **Species Recognition:** In species-rich avian communities, maintaining reproductive isolation is crucial to avoid hybridization. Chemical signals can act as species-specific cues, particularly in situations where visual or acoustic signals are ambiguous, such as in nocturnal or visually similar species (McCubbin 2021). Seabirds, for example, nesting in dense colonies and active at night, may rely on olfactory cues for species recognition (Nevitt 2008).

4.1.2. **Mate Choice:** Chemical signals have been posited as being utilized in birds to judge possible mates. Domestic chicken females, for instance, are attracted towards richer male uropygial gland secretions, possibly as indicators for better immune status or genetic quality (Coria-Avila et al., 2005). The utilization in zebra finches as a foundation for mate selection is possible, though chemical signal nature and functions are still being researched (Faust et al., 2021).

4.1.3. **Sex Signaling**: Sexually dimorphic chemical signals like in duck uropygial gland secretions, can act as sex attractants or indicators of sexual maturity (Sossinka 2011). Seasonally fluctuating chemical profiles associated with hormonal variation reinforce chemical signal functioning in reproductive signaling (Bohnet et al., 1991).

4.2. Foraging:

Olfaction is an important foraging tool for a host of bird species, allowing them to locate sources of food efficiently, especially in tough habitats.

4.2.1. Prey Location: It is established that albatrosses and petrels can locate prey patches in vast distances at sea using olfactory information. One of the key sources of olfactory stimuli for them is dimethyl sulfide (DMS), a sulfur-based chemical discharged by phytoplankton and associated zooplankton and krill (Nevitt et al., 1995). It is utilized by vultures to detect carrion when out of visual sight (Houston 1986).

4.2.2. Prey Discrimination: Insectivorous birds can differentiate prey and non-prey insects based on each respective pheromones and exploit them for foraging for some prey and for foraging efficiency (Amo & Saavedra 2021). The ability to "eavesdrop" on prey pheromones is characteristic of advanced olfaction in some bird species.

4.2.3. Food quality estimation: Birds may use chemical senses to evaluate food quality, identifying rot or nutrient content. It is relatively little studied but could be vital for selecting suitable food and avoiding toxins(Sillman 1973).

4.3. Social Communication:

Chemical signals are involved in avian behavior in aspects beyond foraging and mating, including territorial behavior, recognition, and parent-offspring relationships.

4.3.1. Territoriality: Birds may use scent marking for territory demarcation and defense, but there is relatively little direct evidence for this in birds as compared to mammals. Fecal or uropygial gland secretions can be utilized for territory demarcation and for warning competitors about occupancy (Roper & Jones 1997).

4.3.2. Social Recognition: Birds can distinguish between familiar and unfamiliar individuals based on olfactory cues. Zebra finches, for example, can discriminate between the odors of familiar and unfamiliar individuals, suggesting a role for olfaction in social recognition and potentially kin recognition (Rossi et al., 2017).

4.3.3. Parent-Offspring Recognition: In some bird species, particularly those nesting in dense colonies, olfactory cues might facilitate parent-offspring recognition, helping parents locate their chicks in crowded environments (Caspers et al., 2017). However, the relative importance of olfaction compared to visual and auditory cues in parent-offspring recognition varies across species.

4.4. Defence Mechanisms:

Chemical substances can also serve as defense mechanisms for birds, protecting them from predators or parasites.

4.4.1. Chemical Defenses: Some bird species, like the *Pitohui* birds of New Guinea, possess toxic compounds in their skin and feathers, derived from their diet. These batrachotoxins act as a chemical defense against predators (Dumbacher et al., 1992). Stomach oils of Procellariiform seabirds are also used defensively, being regurgitated at predators as a noxious deterrent (Kuker 2008).

4.4.2. Parasite Resistance: Uropygial gland secretions have antimicrobial and antifungal properties, contributing to plumage hygiene and parasite resistance. Specific chemical components in these secretions may directly inhibit parasite growth or indirectly enhance feather condition, making birds less susceptible to parasite infestations (Haribal et al., 2009). The studies show the importance of chemical substances in different types of avian behaviour.

Table 3: Roles of Avian Chemical Signals in Behavior

Behavioral Context	Role of Chemical Signals	Examples	Reference
Reproduction	Species recognition, mate choice, sexual signaling	Seabird species recognition, chicken mate choice, duck sexual signaling	(Sossinka 2011), (Coria-Avila et al., 2005)
Foraging	Prey location, prey discrimination, food	Albatross foraging using DMS, vulture carrion detection,	(Nevitt et al., 1995), (Houston 1986),

	quality assessment	insectivore prey pheromone detection	(Gagliardo 2013)
Social Communication	Territoriality, social recognition, parent-offspring recognition	Zebra finch social recognition, potential scent marking in territories, parent-chick recognition in colonies	(Roper & Jones 1997)., Rossi et al., 2017), (Caspers et al., 2017)
Defense Mechanisms	Chemical defenses, parasite resistance	*Pitohui* bird toxins, seabird stomach oil defense, uropygial gland antimicrobial properties	(Dumbacher et al., 1992), (Kuker 2008)., (Haribal et al., 2009)

5.0 Challenges and Future Directions

Despite significant progress in understanding avian chemical communication, this field is still in its early stages. Several challenges remain, and numerous exciting avenues for future research exist.

5.1. Challenges:

5.1.1. Complexity of Chemical Signals: The chemical signals in birds are complex chemical components, and isolating individual semiochemicals involved in inducing behavior is thus problematic. The avian chemical secretions are needed for the characterization of complex chemical profiles.

5.1.2. Behavioral Context Dependence: The context-dependent nature may be extreme based on social context, ambient conditions, and receivers' state. Dissecting contextual influence requires behavior experiments that are thoroughly planned.

5.1.3. Integration with Other Sensory Modalities: Birds use multiple sensory modalities, vision and hearing being some of them, for communication. It is vital for comprehending avian communication in a total context to know how chemical signals affect and combine with these other modalities.

5.1.4. Technical Limitations: It is typically technically challenging to study avian olfaction and chemical communication in the wild, requiring sophisticated techniques for capturing and presenting odours and for monitoring behavior in nature.

5.2. Future Directions:

5.2.1. Identification of Specific Semiochemicals: Future research should focus on identifying the specific chemical compounds that mediate avian chemical communication using advanced analytical techniques like gas chromatography-mass spectrometry (GC-MS) and behavioral bioassays.

5.2.2. Genetic and Neural Mechanisms: Exploring the genetic basis of olfactory receptor diversity in birds and the neural pathways involved in processing olfactory information will provide deeper insights into the mechanisms of avian olfaction and chemical communication.

5.2.3. Ecological and Evolutionary Significance: Investigating the ecological and evolutionary significance of avian chemical communication in diverse avian taxa and ecological contexts will reveal the adaptive value of this communication mode and its role in avian diversification.

5.2.4. Conservation Applications: Understanding avian chemical communication could have practical applications in conservation, such as developing olfactory lures for attracting endangered species or using chemical cues to manage avian pests.

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