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Editorial: The importance of olfaction in intra- and interspecific communication, volume II

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Editorial on the Research Topic
The importance of olfaction in intra- and interspecific communication, volume II

Chemical cues were probably the first cues ever used by organisms to assess their environment, and to communicate among them. It is not surprising then, that across the currently living organisms, chemical elements are almost universally used to communicate and to receive information from their environment including other organisms. Their importance has been extensively studied for a great number of taxa, including unicellular organisms and plants. Among the most exciting interspecific relationships mediated by chemical cues we find multi-trophic interactions involving plants, herbivorous organisms, and their predators: arthropods herbivory induces the release of herbivore induced plant volatiles (HIPVs) by attacked plants, and these HIPVs are used by predators of herbivorous arthropods to find their prey. The most known example is that of parasitoids and predators finding their invertebrate prey by following plants' released HIPVs, but similarly, at sea, zooplanktivorous fish and petrel seabirds are attracted by chemical compounds (respectively dimethylsulfoniopropionate and its volatile breakdown, dimethyl sulfide) released by phytoplankton when grazed by zooplankton (Nevitt et al., 1995). Most research dealing with HIPVs involved in multitrophic interactions has been performed in arthropod predators. However, evidence of the use of volatile organic compounds (VOCs) in vertebrate predators has increased in the last decade (Mrazova et al., 2019). However, several aspects are still unknown, as the relative role of visual and chemical cues in prey detection. Research is also needed to disentangle the process of olfactory learning in birds, and how olfaction is integrated with vision in making foraging decisions. Insectivorous birds are generalist predators, and the attraction to HIPVs is not an innate response. Birds need to learn to associate the presence HIPVs with a foraging experience. The study provided by Rubene et al. has shown that great tits did not exhibit any initial preference for HIPV odours, and they did not learn HIPVs faster than neutral plant odours. They also found no differences in learning speed between chemical, visual and multimodal cues, suggesting that the birds learned to associate odours, colours, and multimodal foraging cues with food equally well. Additionally, after learning one cue, they required a significantly shorter learning time to switch to a new cue, with a tendency for particularly faster switching for multimodal cues. Therefore, they concluded that insectivorous birds utilize olfactory and visual cues with similar efficiency in foraging, and that they probably don't have any special predisposition toward the tested HIPVs.

Chemical cues may also help organisms for orientation and navigation. Examples of the use of chemical cues in orientation come from arthropods, fish, reptiles, and mammals. In birds, most experimental studies about the role of olfaction in orientation and navigation have been performed in Columbiformes and Procellariforms. Studies in Passeriformes are scarce and have been mainly performed with migratory species. The study of Mahr et al. has explored whether a non-migratory songbird species, the great tit, use olfactory cues to orientate toward winter-feeding sites within their home range after displacement. Their results showed that birds that received an olfaction-depriving treatment were impaired in homing, as birds with decreased perception of olfactory cues required more time to return to the winter-feeding sites. Their results thus indicate that even in a familiar environment with possible visual landmarks, scent cues might serve as an important source of information for orientation in great tits.

At the intra-specific level, semiochemicals are chemical compounds emitted by organisms that carry a message used in intraspecific communication. Semiochemicals can range from a single compound that induce a fixed response, such as pheromones released by females to attract males, to complex mixtures of chemical compounds that provide information about the sender to which conspecifics may or may not react depending on their motivation or physiological state (Wyatt, 2014). The composition of animal scents may be related to the species, diet, hormonal levels, age, sex, reproductive status, body condition, health state and levels of parasitemia (Amo, 2017). Thus, odours may be used to assess the dominance status of rivals and/or to select potential partners on their qualities. In relation to sex discrimination, previous evidence suggest that birds can assess the sex of conspecific using chemical cues, whereas the preference for the scent of potential partners has not been observed as a general pattern. In the study of Krause et al., the authors explored whether several species of Estrildid Finch use olfaction to discriminate the sex of conspecifics and whether the different species differed in their preference for the scent of potential partners based on the visual and acoustic dimorphism as well as on courtship behaviour. Their results showed sex-specific differences in the preference towards a same-sex conspecific or an opposite-sex conspecific odour among the six Estrildid Finch species. The preference of species was related to the presence or absence of female dance during courtship, with species that possess no female courtship dance, i.e., Diamond Firetails and Bengalese Finches, were more likely to show a preference for the odour of the opposite-sex conspecific, whereas individuals from species with female courtship dance, such as Zebra Finches, preferred more likely the odour of same-sex conspecifics. Therefore, this study suggest that chemical cues might be used during the complex multimodal signalling in mate choice in Estridild Finches, opening a promising line to understand the role of olfaction in mate choice in birds.

Although the study of the role of semiochemical in sexual selection in birds is in its beginnings, in other taxa, such as mammals, there is an ample knowledge about the information that chemical cues can provide in a context of social selection. However, there are still some gaps in this knowledge, as for example, in our understanding of multimodal signalling in non-human catarrhines such as Chimpanzees (*Pan troglodytes*). The study of Jänig et al. tried to fill this gap by studying whether chimpanzee males use olfactory cues to determine the timing of ovulation of females. Chimpanzee females exhibit an exaggerated sexual swelling, known to be a proxy of ovulation, but this visual signal may not reflect the actual timing of ovulation as the maximum swelling is not matching the exact time of ovulation. Therefore, the authors explored whether males may use olfaction to determine when females are more fertile. The results provide evidence that male chimpanzees sniffing behaviour is closely linked to visual information on female fertility, which may allow males to collect information about female reproductive status using multiple modalities. Therefore, they concluded that odours might be part of a multimodal fertility cue, supporting the idea that males monitor both visual and olfactory cues to gain comprehensive information on female fertility to pinpoint the timing of ovulation and thus maximize their mating efforts to ultimately increase their reproductive success.

Some compounds of the individual scent may be genetically determined by, for example, major histocompatibility complex (MHC) or major urinary proteins genes. Therefore, these chemical compounds can provide cues for genetic compatibility when seeking for a mate. The MHC genes may also influence the scent of individuals though modulating the microbioma of individuals. For example, the microbioma found in the uropygial gland secretion of birds has been found to produce similar compounds as found in bird scent (Whittaker et al., 2019). Therefore, microbioma associated with uropygial gland secretion may play an important role on avian intraspecific chemical communication. However, how social environment influence such microbioma and the avian scent remained unstudied. In the interesting study of Whittaker et al., the authors experimentally manipulated social interactions in captive dark-eyed juncos (*Junco hyemalis*) to assess the relative influence of social interactions on uropygial gland microbial composition and the resulting preen oil odor profiles. The authors observed changes in volatile compounds after the birds had been housed in pairs, but those changes disappeared after birds were located into flocks. Therefore, their results suggest that hormonal changes related to breeding condition were the most important factor in these patterns. In conclusion, their results showed that shorter-term changes in social environment of birds do not have a strong effect on uropygial microbiomes. Furthermore, these shorter changes in social environment do not influence the resulting preen oil volatile compounds. In contrast, early life social environment of nestlings and long-term social relationships have been shown to be important in modulating uropygial gland microbial communities (Whittaker et al., 2016).

Other compounds of animal scent are related to body condition, health state and levels of parasitemia. For example, female mice are able to detect and avoid the scent of males infected by influenza virus, or gut parasites (Beltran-Bech and Richard, 2014). Assessing the infection status of a potential partner may able females to avoid been infected, and therefore, may be under a strong selection pressure. However, chemical cues may not only be detected by conespecifics but they can be eavesdropped by heteroespecifics. For example, predator and parasitoids can detect the chemical cues that their prey or host emit to locate them, implying a cost of signalling to the transmitter. Chemical cues emitted by animals may not only signal their presence, but they may also provide interesting information to predators or parasitoids. For example, predators may benefit to ascertain the infection status of a prey if the pathogen can be transmitted to the predator though prey ingestion. However, studies examining how natural selection has modulated predator ability to ascertain prey infection remains scarce.

In relation to the assessment of disease by heterospecific animals, the review of Piqueret et al. shows how different taxa have been used by humans to diagnose human sickness. Traditionally physicians used olfactory cues to diagnose sickness by smelling the breath or the urine of patients, and it is known that dogs or small mammals can be used as biodetectors of human illnesses such as cancer, infections by virus or bacteria. However, the use of invertebrates as biodetectors has received less attention. Piqueret et al. provide an extensive revision of current literature on olfactory detection of diseases by invertebrates. For example, the nematode *Caenorhabditis elegans*, the Fruit fly (*Drosophila melanogaster*), the Honey bee (*Apis mellifera)* and *Formica fusca* ants have been used in detecting cancer, tuberculosis and/or sepsis. Some species do not need to be trained and can express natural behaviour toward specific samples, as the nematode *C. elegans*. Other species, such as the fruit fly, can present mutations on olfactory receptors used for disease detection. Eusocial insects can transmit learned information to conspecifics. Therefore, these species allow to train only a small number of individuals per colony that will later go on to share the information with naive nestmates. Although the use of olfactory detection abilities of invertebrates is at an early stage, invertebrates have a significant potential when it comes to implementation, replication, rapidity, and efficiency of disease detection. Therefore, the authors point out the need of further efforts to make use of the rich diversity of species and behavioural and neurophysiological protocols available in invertebrates, to develop efficient new assays for the early detection of deadly diseases.

We hope that the contributions presented in this Research Topic will provide state of the art examples of the role of olfaction in animal behaviour and promote further research in this framework.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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