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From Molecules to Perception: Philosophical Investigations of Smell

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Abstract

Theories of perception have traditionally dismissed the sense of smell as a notoriously variable and highly subjective sense, mainly because it does not easily fit into accounts of perception based on visual experience. So far, philosophical questions about the objects of olfactory perception have started by considering the nature of olfactory experience. However, there is no philosophically neutral or agreed conception of olfactory experience: it all depends on what one thinks odors are. We examine the existing philosophical methodology for addressing our sense of smell: on the one hand appeals to phenomenology that focus on the experiential dimensions of odor perception and on the other approaches that look at odor sources and their material dimensions. We show that neither strategy provides enough information to account for the human sense of smell and argue that the inclusion of the missing dimension of biology, with its concern for the function (or functions) of olfaction, provides the means to develop a satisfactory and empirically informed philosophy of smell.

1 | THE PHILOSOPHICAL STUDY OF OLFACTION: A ROADMAP

In thinking about perception and the senses, philosophers have had very little to say about smell—until recently. Theories of perception have been framed almost exclusively in terms of vision (Burge, 2010; Matthen, 2005) with scant regard for other senses and a hope that minor modifications can accommodate them in a general account of

Ann-Sophie Barwich and Barry C. Smith have contributed equally to this work.

perception worked out for the visual case. There are notable exceptions. Merleau-Ponty (1965(1945)) characterized perception in terms of touch, kinanesthesia, and proprioception as well as vision, and Strawson (1959) considered whether a creature with purely auditory experience could, on the basis of hearing alone, conceive of an objective world of particulars; i.e., a world consisting entirely of sounds. (His answer was no.)

But beyond sight, hearing, and touch, the bodily senses of smell and taste received little attention. Since Galileo and Locke, these senses were thought to disclose secondary qualities beyond the remit of science; a mere philosophical curiosity. Olfaction, in particular, came in for the greatest disdain from philosophers. Étienne Bonnot de Condillac (1930[1754], p. 171) noted that: "Of all the senses it is the one which appears to contribute least to the cognitions of the human mind." Immanuel Kant (2006(1798)) insisted that smell is the "most dispensable" and "most ungrateful" of the senses, and even Charles Darwin (1874, p. 17) considered it as being "of extremely slight service" to humankind. Strawson (1959, p. 64) was prepared to describe the senses of smell and taste as "strikingly more trivial than the others" and to see their loss as having no impact on the perception of the world: "One does not see the world differently if one has a cold."

Why has the study of olfaction been viewed as insignificant or irrelevant, and why has smell, until recently, been mostly neglected in the philosophy of perception? We show that this tendency has underestimated the influence of our sense of smell on cognition and emotion, and therefore has failed to characterize the place of smell in our lives.

In addressing our sense of smell, we will draw on recent philosophical work on olfaction to outline the challenges it presents. The work considered here is part of a renewed interest in the non-visual senses that challenges the idea that visual perception alone provides the central case for a theory of perception.[1] In the visual case, the problem of perception is understanding how visual experience gives us access to a spatial layout of 3D objects in our immediate surroundings (Gibson, 1966; Marr, 1982). By contrast, the study of sounds, smells, and tastes often starts with the nature of auditory, olfactory, and gustatory experiences before attempting to relate these experiences to the sources or stimuli giving rise to them.

Olfaction offers a particularly challenging subject for philosophers. The same stimulus of volatile airborne molecules can elicit markedly different olfactory experiences (Barwich, 2019; Herz & von Clef, 2001; Sinding et al., 2015). Such perceptual variations can involve the pleasantness of an odor, its intensity, and its associated odor quality (meaning the particular odor identity it has for us). For example, Peter may perceive the smell of ethyl citronellyl oxalate ($C_{14}H_{24}O_4$) as strong and musky, whereas Mary tells you that she finds its odor has a light, sweet, and fruity-pear note. Is one of them right, are both right, or is there simply no fact of the matter to discuss?

In response to the high degree of variations between individual perceivers' experiences, philosophers and scientists are often tempted to declare that smell is a purely subjective phenomenon. The move made here is analogous to discussions in ethics where, in the face of differing judgments about whether something is morally right or wrong, some philosophers will conclude that moral claims are purely subjective, expressive of attitudes. However, the olfactory and the moral cases are not analogous: scientific evidence can cast light on why individuals diverge in their responses to the same odor sources without leading to the conclusion their judgements are only expressions of their own internal states. Moral disagreements are often explained with an appeal to cultural differences (Brandt, 1996). And while, in comparison,[2] variations in olfactory experience may be partly explained by cross-cultural factors, it is far more likely that causal-mechanistic, and ultimately biological explanations, such as the vast genetic heterogeneity of the olfactory system in the human olfactory genome will account for these differences. (Barwich, 2019; Trimmer et al., 2019; Wysocki & Beauchamp, 1984). Individual difference in perception is not the same as subjectivity: a point frequently missed by philosophers and scientists alike. To conceive of smell as subjective goes beyond claims to individual difference and rests on an acceptance that: (1) the only way to characterize a smell is via a subject's experience of that smell, (2) experiences of smells are not perceptions but inner sensations, and (3) sensations of smelling are answerable to nothing but themselves, i.e., they are not about anything else. We shall explore these assumptions and assess the arguments for them.

Contemporary philosophical work on olfaction largely centers on three topics:

- What are smells?
- What are the objects of olfactory experience?
- What is the nature of olfactory experience?

The first topic is a metaphysical inquiry into the nature of smells as either: objects; properties; stuffs; molecular structures of compounds; processes or sensations (Barwich, 2014, 2018; Batty, 2014; Lycan, 2000; Millar, 2019; Mizrahi, 2013; Scruton, 2007; Young, 2016). It is worth adding that modern philosophical accounts have paid less attention to the prominent hedonic dimension of smell but primarily engaged with the nature of odor quality and whether it presents us with objects or properties in experience.

Two competing perspectives have framed the contemporary philosophical study of smell in arriving at an answer to the metaphysical question of what smells are. First, some philosophers begin with answers to the question about the objects of smell experiences. Their project is part of the epistemology of mind, asking what sorts of things does smelling give us knowledge of. Are they odor sources, odor clouds, odor profiles, odor molecules (Batty, 2010a; Richardson, 2013; Smith, 2013; Young, 2016)? Philosophers pursuing this strategy tend to center their analysis on odor sources and molecules to ask what must go on for humans or other animals to perceive them. Second, other philosophers reject this inquiry, convinced that our experiences of smell are sensations, not perceptions, that only enable us to know our own odor experiences (Lycan, 2000). These philosophers believe that our only guide to smell is the subjective experience of smelling something - the 'what it's like' to, say, smell a rose. Only by examining these experiences and having something to say about what these experiences are experiences of, can we come to say anything about what smells are and how we can know them. To settle this matter, we need to turn to questions about the nature of olfactory experiences (Aasen, 2018; Keller, 2017; Lycan, 2000; Richardson, 2013; Smith, 2019). This topic is part of the philosophy of mind; and for many, it constitutes the only means to arrive at answers in the two former types of inquiry.

However, there is no agreed, philosophically neutral starting place: it all depends on how one conceives the object of study, that is, on one's conception of what odors are. There are both objectivist and subjectivist views of odors on each of the strategies mentioned above, and no consensus on which approach is best. Some theorists believe that smelling is primarily an interoceptive or inward-directed phenomenon: a communing with our own experiences. The experience of smells, on this view, is similar to sensations of pains – and not the perceiving of anything external to ourselves. For others, it is evident that smelling is best viewed as an exteroceptive or distal sense providing us with knowledge of things in our environment: potential mates, predators, food sources, and involved in guiding navigation toward (or away from) these things. These accounts of olfactory perception are likely to draw on chemistry and neurobiology to fill out our understanding of olfactory perception. And some are prepared to revise our common-sense views about what it's like to smell something in this context.

What all strategies should agree on is that, in normal conditions, smelling occurs when we take in odor molecules from our immediate environment. Whether that results in mere changes in our internal states, the perceiving of odor trails or the acquiring information about odor sources remains debatable. Still, as we shall argue, a fully satisfactory philosophical account of the human sense of smell requires us to go beyond phenomenology and the chemistry of odors or odorants (the technical term for the chemical stimulus) and to appeal to the neurobiology of olfaction.

Questions of philosophical methodology will be in view throughout this article. We begin by discussing the views of those who base their conclusions on the nature of smells and what olfactory experience can tell us about the character of odors. What is striking here is that despite being based on appeals to phenomenology, there is no agreement among philosophers on the phenomenology of olfactory experiences or what reflections on these experiences can tell us. Next, we consider strategies that start with a discussion of odor sources and their material dimensions. We show that neither accounts of odor experience nor odor molecules alone provide us with enough information to

account for the human sense of smell. The final section introduces the missing dimension of biology, with its concern for the function (or functions) of olfaction, which is required to help us pin down what an odor is.

Some analytic philosophers of smell resist the appeal to scientific evidence in providing a philosophical account for our sense of smell, arguing that scientific findings should not lead us to revise our everyday conception of smell. We show that these arguments are at best inconclusive, but they are also based on a mistaken and inadequate account of what reflections on our ordinary experience reveals to us. As such, our ordinary conception mischaracterizes the target of inquiry. The science of olfaction can bring to light fundamental features of olfactory experience not transparently revealed at first in our everyday way of thinking about our sense of smell. A scientifically informed understanding of smell enables us to improve our chances of arriving at a fully satisfactory account of the nature of smell. First, it recognizes a broader range of facts to be accommodated. Enabling us to refine both the description of the phenomena and the type of account we can give of our sense of smell provides a means to adjudicate between competing philosophical theories of olfaction. Furthermore, by highlighting the impoverished understanding of the perceptual experience of smell that philosophers without the benefit of empirical knowledge begin from, we can perhaps cast light on why olfaction was previously so neglected and disdained. By contrast, as we hope to show, an empirically informed philosophy of smell can point to the relevance and value of its findings to other questions in the philosophy of perception and mind, in addition to the philosophy of science.

2 | THE NATURE OF OLFACTORY EXPERIENCE

Many philosophers regard the study of smell as part of the philosophy of mind. For in the absence of any other way to individuate odors or smells (many use these terms interchangeably), the only way to delineate the subject matter of the philosophical study of odors is via an account of odors as they appear to us in experience.

On this view, our understanding of the nature of odors should ultimately be answerable to how they subjectively appear to us when we undergo an experience of smelling. Whether this means that odors only exist in the mind depends on how one thinks about the mind's relationship to the world. Ever since Galileo distinguished between primary and secondary qualities (Martinez, 1974) — the former being aspects of nature and the latter being sensory qualities that had no resemblance to matter — many philosophers and scientists have treated sounds, smells, and colors as belonging wholly within the mind of perceivers. And although secondary qualities can be taken (as Locke did) as powers in the object to produce ideas of sounds, smells or tastes, smells and the like can only be known to us through our experience of them.

Alternatively, if one believes (as direct realists do) that perception allows for unmediated access to things in our surroundings, we may suppose that we perceive odors as part of the world which are only knowable as they appear to us in perceptual experience. Of course, it is also possible to retain the idea of direct and unmediated access to smells in experience because the nature of smells is exhausted by odor experiences; i.e. where odor experiences are sensations not perceptions, and smells are wholly within the mind. Both options begin with the starting point that the only way to get at the nature of smells is via our experience of them. Now, if we adopt this methodology, what do these experiences reveal? Do they, for instance, tell us which of these accounts of odor is right? Before asking these questions or adopting this methodology, we need to ask whether it really is possible to know our experiences of smell fully.

A crucial first step is to characterize olfactory experience through the phenomenology of our experience of smelling. Here, it is assumed that phenomenology is a guide to the nature of those experiences and ultimately to the nature of smells themselves. But how well does phenomenology serve us in our inquiry into smell?

William Lycan (2000, p. 281), one of the first contemporary philosophers to address the nature of olfaction, tells us that: "Phenomenally speaking, a smell is just a modification of consciousness, a qualitative condition or event in us." Unlike vision and hearing, which relate us to distal parts of our environment, smell can only give us knowledge

of ourselves, of how things are with us. This conception of the experiences our sense of smell provides us with was widely shared in the 18th century. For example, Thomas Reid (1764, p. 12) states that:

> The experience of smelling is about nothing but itself.; A smell does not have any existence but when it is smelled…It is a sensation; and a sensation can only be in a sentient thing.

In Reid's conception, a sensation does not represent anything. It does not tell us about anything but itself. It is a purely subjective state. de Condillac (1930[1754], p. 175) was also confident in pronouncing what an experience of smelling could *not* provide: a smell cannot afford any ideas of "shape, extension of anything outside itself, or outside its sensations." Based on self-reflection, these philosophers feel confident in pronouncing the character of smell experiences and, hence, on the nature of smells.

However, contemporary philosophers have experienced their acts of smelling quite differently. Batty (2011, p. 172) observes that we experience odors as being in our vicinity, around us: the experience of smelling is telling us that "that there is something or other here with certain properties." Mizrahi (2013, p. 9) notes that "smells seem to be vaguely located around the perceiver." Solveig Aasen (2018, p. 3) believes that "one simply experiences smells as being at a distance or direction" without being at any particular distance or direction. And Louise Richardson (2013, p. 410) goes further, proposing that because smelling requires sniffing and in sniffing we experience "odors being brought into the nose from without," so we conceive the sniffed odors only as immediately external to us. (However, we are not required to sniff in order to smell as Gibson (1966) noted, we smell because we breathe.) Smith (2017) and Aasen (2018) argue on phenomenological grounds for the spatial character of olfactory experience, of there being a rough distance, near or far, the smell of a lit cigarette is from us. Others consider it evident that odors emanate from their sources: the rotting garbage, the drying paint, the cut grass (Young, 2016). And others think of odors in terms of perceptual expressions that act as memory tags for experiences with a material stimulus that, in its occurrence, is promiscuous and unpredictable (Barwich, 2020).

The contrast between different philosophers' phenomenological observations is striking. In a previous pair of Philosophy Compass articles, Batty (2010a, 2010b) has detailed the specific challenges that olfaction poses for representational accounts with the question of whether odors present objects or properties. Here, we shall complement her analysis with a closer focus on issues of philosophical methodology that underlie possible ways of addressing these challenges.

Even if there was agreement about our smell experiences, Aasen (2018, p. 2) claims that: "The phenomenology can be described accurately without specifying what the object of experience is," although the correct characterization of the phenomenology will put constraints on the object of experience. Furthermore, she argues that there is no single unified nature to all olfactory experiences. Another flaw in the phenomenological approach to smell is the absence of the daily occurrence of conscious olfactory experiences not recognized as such; namely, the contribution olfaction makes to the multisensory perception of flavors (Smith, 2015). We will return to this missing aspect of our experience of smell in Section 4.

Together, these considerations pose an insurmountable problem for the current strategy in the study of smell: if the nature of olfactory experience is meant to be our guide to the nature of odors, and there is no agreement about the character or extent of olfactory experience, and no guarantee that such experiences pick out a single object of experience, then we are not in a position to make uncontested claims about the nature of odors.

Let us then turn to other guides to odor and odor experience, namely the volatile molecules that cause us to have such experiences.

3 | ODORS AND ODOR SOURCES

Why not center philosophical analysis of olfactory perception on the material basis of odor sources? Here we shall examine some of the chief considerations in support of defining the nature of odors via their source materials.

Talking about the objects of olfactory perception has been notoriously ambiguous in scientists' and philosophers' writings. In response to this challenge, Lycan (1996) introduced a three-level analysis to clarify what we refer to when we talk about "objects" in olfactory experience: physical macro-objects and micro-objects, and mental objects.

In our everyday experience, we usually notice odors emitted from objects like lemons or roses and also the funky smell of tomato leaves during Californian summer or the steaming goulash of one's aunt. Lycan characterizes this level in terms of the ordinary objects of our experience, i.e., the "macro-objects" from which the chemical stimulus emanates as clouds of molecules.

The chemical stimulus constitutes another level of analysis and presents us with the "micro-objects" that act as a physical cause on the sensory system of the perceiver. Confirming that pejorative views on the abilities of the nose are outdated, humans can detect a mind-boggling number of structurally different chemicals (Ohloff et al., 2012). Recent computational estimates even allude to the possibility of humans being able to distinguish about one trillion odor stimuli (Bushdid et al., 2014), although this fantastic number has been debunked (by Meister, 2015; and Gerkin & Castro, 2015; response by Magnasco et al., 2015). Methodological questions surrounding the calculation of odorants aside, the number is sky-high. Besides, the chemical stimulus of smell differs from the visual stimulus in several significant ways also relevant for philosophical investigations of its perception, which we shall exemplify later in this section.

We can also talk about odor objects in terms of the mental objects associated with an olfactory experience, such as the image of a "banana" forming in our minds when we smell heptyl acetate ($C_9H_{18}O_2$). Indeed, the macro-source of a smell need not be visible for us to associate an olfactory experience with a mental object. For example, the molecule cis-3-hexen-ol ($C_6H_{12}O$) can elicit the perception of freshly cut green grass even when one is not walking outdoors but sits in a sterile laboratory environment.

This three-level analysis serves as a valuable analytic tool to separate the various meanings of odor objects. The inevitable follow-up question — how are these levels related? — consequently leads us further down the rabbit hole, revealing why smell is philosophically intriguing and ripe for modern perspectives on the nature of sensory experience. It turns out that these three levels refuse to line up neatly and currently do not provide a coherent picture of the link between odor qualities and their source materials.

Three challenges attest to this. The first challenge involves the relationship between percepts (level 3) and microstructure (level 2). Will the same molecular structure give rise to the same, or similar enough, odor quality? The empirical answer is no. It is not uncommon to encounter structurally different chemicals within the same category of odor quality, and fragrance chemists have documented an array of widespread irregular structure-odor relations (Rossiter, 1996; Sell, 2006). A case in point is "musk," a popular ingredient in perfumery (Figure 1). Musk odorants are markedly diverse in molecular structure with non-overlapping causal features, such as specific atom groups (e.g., the presence or absence of nitrogen musks) and stereochemical configuration (i.e., the geometrical "shape" of a molecule). Another striking example is Karanal ($C_{17}H_{30}O_2$), a molecule with an ambergris scent lacking structural similarity to most other known ambergris odorants (Barwich, 2015). Odor quality can be associated with various microstructures and vice versa.

Another challenge concerns the chemical clouds (level 2) that come from ordinary objects (level 1). Many macro-sources emit hundreds of different volatile compounds that can vary in composition. For example, flowers tend to emanate different plumes of volatiles in the course of a day or a year, such that a rose at any other time may not smell as sweet. Other factors of variation involve differences in the chemical composition of species (especially in plants) and brands of objects (say, coffee), or the impact of environmental factors such as temperature and humidity on the release of volatiles from a source object, and also the developmental cycles that organic complexes undergo (such as riping and decomposition) or the temporal sequence in artificial compositions (such as perfumes). The upshot

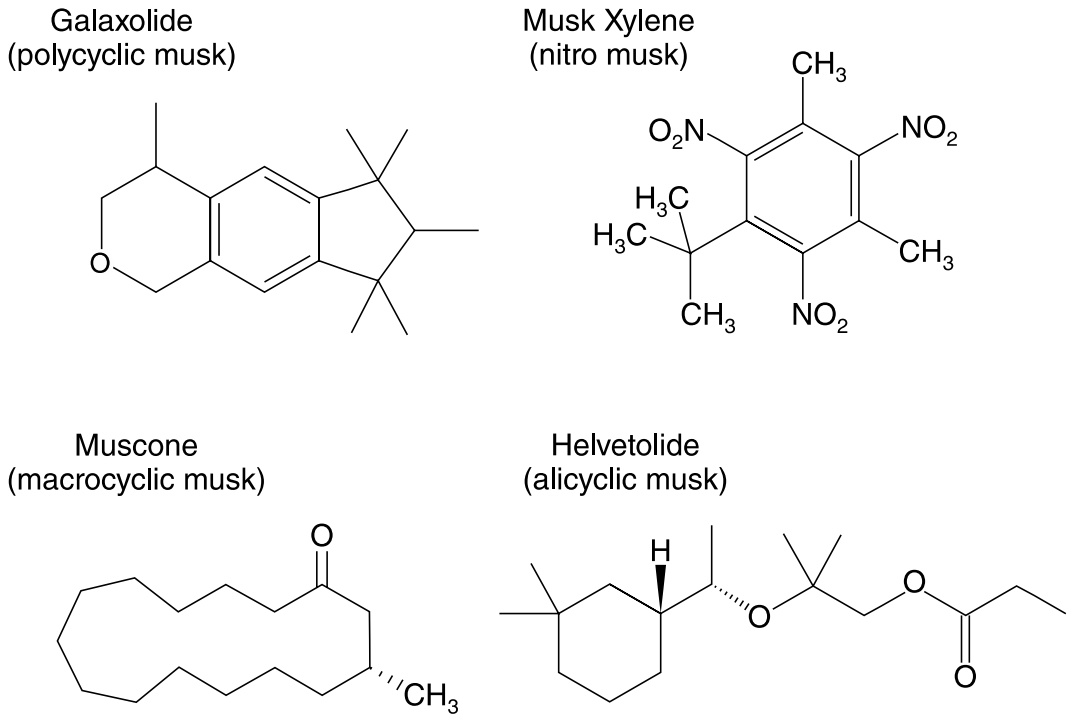

FIGURE 1 (image Barwich, 2020): Examples of structurally diverse musk molecules

here is that ordinary objects can give rise to multiple and variable sensory qualities because of their changeable emissions of volatile components.

A third challenge will be of particular interest for philosophical investigation. Does our qualitative experience of a smell and our mental object associated with its experience (level 3) differ when the source object (level 1) is invisible and when we are only confronted with its microsource (level 2)? It turns out that this is the case, and this phenomenon was first documented by Hans Henning (1916), an early pioneer in the psychology of smell. Noticing a difference in people's reports on odor and variations in qualitative descriptions of an olfactory experience, Henning distinguished the "object smell" (with visible source) from the "given smell" (with unknown origin) of an odor. This distinction also resonates with everyday experience; for example, when you smell ylang-ylang, you will perceive a distinct qualitative sensation - even without knowing what ylang-ylang looks like or without knowing what ylang-ylang is.

In the face of such inherently cross-cutting and non-linear relations between physical odor sources and our experience of odor quality, we find ourselves at conceptual crossroads. To simplify the philosophical analysis of odor, perhaps the starting point should involve a more reductive stimulus-response model to determine the nature of smelling. That is a strategy we find in Young's (2016, 2020) "Molecular Structure Theory" (MST), which centers philosophical analysis of odor objects on the nature of the chemical stimulus. This view will appeal to philosophers who wish to discuss the possibility of objectivity in odor perception. However, it certainly does not guarantee such objectivity as long as it remains unspecified just how the chemistry of odor molecules, as a cause of odor perception, relates to the content of olfactory perceptual experience.

Young's account resonates with some scientists' emphasis on the chemical stimulus (Keller et al., 2017). However, other scientific and philosophical reports dispute the notion that the nature of olfactory experience is principally accounted for by the chemical stimulus or that the chemical stimulus constitutes the key element of analysis in olfactory neuroscience (Barwich, 2019, 2021; Poivet et al., 2016, 2018). Accordingly, we shall briefly outline three challenges for MST.

A vital issue with chemical theories of odor is that chemistry cannot predict a molecule's smell (Barwich, 2020; Keller & Vosshall, 2016; Sell, 2006). Indeed, knowledge of chemical features in isolation — meaning independently of biological responses — cannot even tell us whether a molecule is odorous:

> it is nearly impossible to predict whether a given molecule will be odorous and what its odor quality might be from the chemical structure alone. Although all odor molecules are typically organic compounds of low molecular weight, they may be aliphatic or aromatic, may be saturated or unsaturated, and may have any of several polar functional groups. However, there are many molecules that conform to those characteristics, which are nonetheless odorless, to humans and other animals. (Poivet et al., 2018, p. 1)

The unpredictability of odor from chemical structure is more than a practical problem for scientists to solve with the advance of better data analysis tools (Barwich & Lloyd, 2022). Instead, it suggests a conceptual conundrum of relevance also to philosophers. How can we establish philosophical theories of odor via their material sources if the causal basis of smell (involving models of both stimulus chemistry and the biological detection mechanism) remains subject to scientific development (Kurian et al., 2021)? This conundrum need not put an end to philosophical investigations of odor. On the contrary, such unresolved scientific debate on the causal basis of olfaction invites empirically minded philosophers to participate meaningfully in experimental research by investigating the conceptual foundations of ongoing empirical inquiry.

Another limit of MST is rendered visible when we take a closer look at variations in the perceptual expressions of a chemical stimulus. The same molecule can elicit different perceptual experiences across individuals and within the same subject at different times. This variability indicates that we must include factors other than stimulus chemistry to account for odor perception. Moreover, these other factors, denoting biological and psychological mechanisms of odor perception, might have explanatory priority over chemical theories of odor (Barwich, 2020).

Perfumers, for example, will tell you that people's perception of odor sources may vary because many odorants can communicate more than one odor note (e.g., see an interview with the master perfumer Christophe Laudamiel in Barwich, 2020, Ch. 3). Consider the smell of sulfurol, an odorant with animalic, yeasty, nutty, milky, and sulfurous odor notes; or take the scent of linalool which carries floral, citrusy, and spicy tones, etcetera. Ultimately, each odorant contains multiple qualitative notes that allow for varying olfactory experiences. Thus, when Mary perceives ethyl citronellyl oxalate's odor as musky while Peter insists it has a sweet, fruity pear note, they can both be right because ethyl citronellyl oxalate carries both odor notes, such that Mary and Peter may selectively process and attend to a different aspect of the same odorant. To adopt the American poet Walt Whitman's vivid phrase: an odorant contains multitudes. This inherent qualitative multitude shows how the same chemical stimulus can facilitate multiple odor images in people as contingent on prior experience, the context of odor exposure, and the influence of cross-modal cues on perceptual object formation.

Some might object that this qualitative multitude of odorants may still allow for a chemical theory of odor. However, we encounter a variety of factors crucial to odor perception that continue to make a primarily chemical account implausible. One such aspect concerns genetics. For example, a recent study by Eriksson et al. (2012) has shown that people vary in their liking and their qualitative experience of cilantro (coriander) because of a mutation near one of the receptor genes. Genetic variation of the olfactory system in the human genome demonstrates that the receptors determine odor quality and that, as Dennett (1988) would say, "Properties that 'seem intrinsic' at first often turn out on more careful analysis to be relational." (To be sure, these examples are not meant to be exhaustive but illustrate that variations in the experience of odor are to be determined by the causal disposition of the stimulus in line with the sensory system's causal conditions and affordances.)[3]

The last case, demonstrating that the chemical basis of odor is an insufficient basis for theories of odor perception, provides examples that show olfactory percepts as products of "computational" processes in the brain. These examples resonate with philosophical arguments looking at the processing of color in the visual system, where we

know that many colors we can experience need not have an associated wavelength (Chirimuuta, 2015). For instance, unlike our perception of red or blue, the experience of pink is not caused by a particular wavelength in the visible spectrum of light. Instead, it results from a "calculation" by the human sensory system: "white light minus green light." Understanding how we experience color is not a matter of studying wavelength in isolation but determining how retina receptors process wavelength. In other words: modern theories of color vision are grounded in the coding principles of the color receptors that determine the physical features further processed by the sensory system.

The same principle holds for olfaction, as it becomes clear with the example of "olfactory white," a fascinating phenomenon discovered recently (Weiss et al., 2012). Olfactory white (in analogy with white noise in audition) describes a distinct odor quality with no associations to any known ordinary object. Its unique perceptual quality was given the label "Lorax." The critical thing to understand about Lorax is that it is not tied to a specific molecular structure or source. Lorax emerges when you mix a minimum of thirty odorants with non-overlapping chemical features (such as particular atom groups) at equal intensity. Remarkably, any combination of odorants will do under these circumstances. Plus, when you blend sixty molecules according to the same principle, you will also end up with Lorax. The same phenomenon occurs when you mix ninety molecules, etcetera. But now consider the following observation: when you arbitrarily divide a mix of sixty (or sixty-plus) odorants into two sets, you end up with two blends smelling of Lorax, again! The point is that olfactory white cannot be accounted for by a chemical theory of odor but by reference to the principles of the sensory system processing the stimulus.

So how do odor receptors encode chemical information? It turns out that this remains a complex issue still under scientific investigation (Barwich, 2021). Short of a conclusive answer, what is relevant to the discussion about MST in our discussion here is the question of whether odor receptors really respond to the same properties by which an analytical chemist would model a molecule. The short answer is no (Poivet et al., 2016, 2018; Barwich, 2020, Chapter 6; forthcoming). Consequently, any account of what the object of odor perception is must center its analysis on the sensory system that processes the chemical stimulus, not the chemical stimulus.

Next, we shall show how engagement with scientific perspectives on the biology of olfaction enriches philosophical theorizing about the human sense of smell.

4 | THE FUNCTION(S) OF OLFACTION

From a broader perspective, the pathway of smell looks deceptively simple (Figure 2). It consists of three main stages: receptors, olfactory bulb, and olfactory cortex. We start smelling when odorants traveling up the nasal cavity interact with the olfactory receptors, situated in the sensory nerves behind the bridge of the nose in a cell layer in a patch of skin called the epithelium. This interaction translates chemical information from the environment into electrical signals in the brain. This electrical signal gets sent to the olfactory bulb in the brain's inferior frontal lobe. You may compare the bulb to an orchestra, where the signal is organized into groups (percussion here, strings there) and further sharpened before being sent to the olfactory cortex. This signal is further processed and distributed in the olfactory cortex, the so-called piriform cortex. The primary olfactory cortex acts like a conductor that directs the signals from the bulb to a variety of other brain areas, including the amygdala (valence), the entorhinal cortex (navigation and episodic memory), the insular cortex (bodily awareness and primary taste cortex) orbitofrontal cortex (integration with taste, touch and hedonic response), the hippocampus (memory), and many others. That is roughly how the olfactory symphony is played.

Scientific opinions diverge about the principles of odor processing on the cellular level and its functional role on a behavioral level. Is olfaction's function (or functions) to:

- evaluate pleasant and unpleasant smells (Yeshurun & Sobel, 2010),
- categorize qualitative kinds like floral, fruity, woody, etc. (Koulakov et al., 2011),
- identify mates and predators (Herz & Inzlicht, 2002),

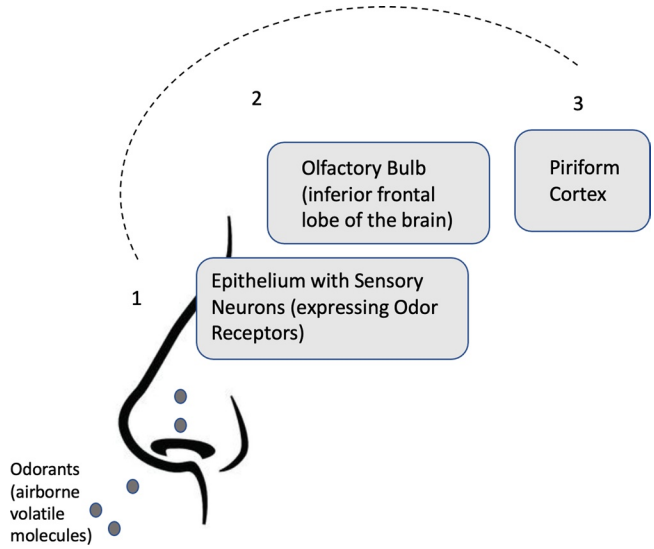

FIGURE 2 (Simplified) Olfactory Pathway. Odorants travel up the nasal cavity to the epithelium with the olfactory sensory neurons (OSNs) expressing the odor receptors. The OSNs transmit the signal to the olfactory bulb at the inferior frontal lobe of the brain. This signal is further projected to the piriform cortex, the largest domain of the olfactory cortex.

- kin recognition (Porter, 1998),
- identify the emotions of others (Chen & Haviland-Jones, 2000; Pause, 2012),
- navigate the environment (Bao et al., 2019; Poo et al., 2022),
- or detect subtle yet behaviorally relevant chemical changes in the environment (Barwich, 2019; Köster et al., 2014),
- guide successful food choice (Auvray & Spence, 2008; Smith, 2015; Yeomans, 2006)?

Our sense of smell serves all these functions.

Scientific perspectives, including contemporary empirical disagreements, can inform philosophical studies of odor (see Barwich, 2020). Conversely, empirically grounded philosophical outlooks may complement scientific explanations of discordant data and conceptually clarify divergent models.

To facilitate cross-disciplinary exchange it is important to explore the hidden methodological choices that inform both the scientific and philosophical studies of odor. To begin with how feasible is it to analyze olfaction with concepts derived from our study of vision? Science routinely advances by drawing analogies between different systems (Hesse, 1963). However, these analogies can break down with further insight into the characteristics and dynamics of a system under investigation and, over the past years, it indeed transpired that vision and olfaction are markedly different in their neural organization (Barwich, 2020).

Biological differences between the olfactory and visual systems might account for a variety of the perceptual effects that have often puzzled philosophers in their study of odor. We shall give two examples here. First, one significant characteristic of the olfactory system is its high genetic diversity in humans and other animals (except for laboratory model organisms, bred for genetic homogeneity). Such genetic variations, as mentioned earlier, have been systematically linked to perceptual variations in human olfaction (Mainland et al., 2014; Trimmer et al., 2019).

Let's look at the last point in more detail. The genetic diversity in humans concerns the genes expressing the olfactory receptors situated in the sensory neurons in the epithelium of the nose. Humans have about 400 different receptor types (the precise number again is in flux), whereas, in comparison, we have 3 types of cone receptors for color vision. Genetic differences in olfactory receptor genes can have various effects on sensory processing and, in

turn, perceptual responses to odors. One of these effects is that individuals vary in terms of the receptors expressed in their epithelium; in other words: people have different receptor repertoires or "response kits" in their noses. Now, the reason why we also overlap in most of our responses to odors, despite such divergence, links to the mechanism of odor detection at the periphery. Instead of a "one receptor binds one molecule" interaction, olfactory receptors respond to odorants in a combinatorial fashion: meaning one receptor responds to different odorants by different chemical features, and various receptors recognize one odorant via different chemical features (Malnic et al., 1999). So even if Mary expresses a receptor gene that Peter does not express (or vice versa), they can still detect the same odorant via a set of other shared receptors - while they also may differ more subtly in the qualitative experience of that odor molecule (Figure 3).

Another effect resulting from genetic diversity concerns differences in receptor sensitivity toward odorants. Consider androstenone, a pig pheromone that people perceive markedly differently (Wysocki & Beauchamp, 1984). Some people find androstenone unpleasant and characterize its smell as urinous, or think it smells of body odor. Other people describe its smell as pleasant and attribute it a floral quality, while others cannot smell it at all. In effect, the same odorant causes varying odor experiences across people. The diverging perception of androstenone

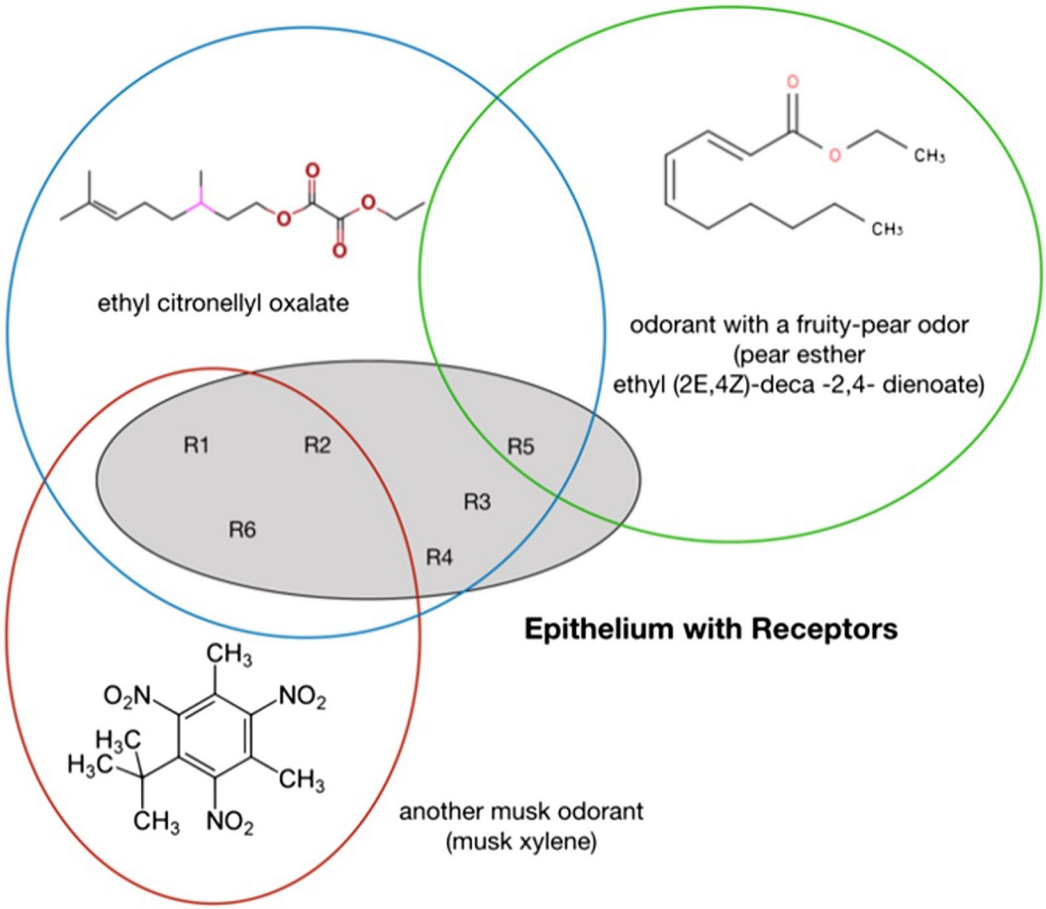

FIGURE 3 (image Barwich, 2021): Overlapping receptor activity in the combinatorial coding of different odorants. Olfactory receptors {R1-R6} overlap in their response tuning range to different odorants. If Mary does not express receptor R5, her qualitative experience of ethyl citronellyl oxalate may differ from Peter's. (This is a hypothetical case for illustration purposes. The binding range of most olfactory receptors remains to be studied. However, see the work on receptor 'de-orphanization,' for example, in Matsunami (2016))

has been linked to genetic diversity in addition to other factors, such as familiarity, sex, and age (Keller et al., 2007; Mainland et al., 2014).

A second striking characteristic of olfaction is its capacity for adult neurogenesis. Olfaction is one of the few brain systems regenerating nerve cells throughout an organism's lifespan (Brann & Firestein, 2014). One notable effect linked to this characteristic is that the expression of receptor sets can also change throughout life. Expression profiles of human odor receptors are contingent on age, diet-related changes, and odorant-induced activity levels (Monahan & Lomvardas, 2012; Pletcher, 2009). The olfactory system tunes itself to the physiological and ecological conditions of the perceiver, so much so that when people change their diet or habitat, the nose follows suit.

Examples like these illustrate why philosophical studies of odors benefit from scientific insights into the biological processes that undergird human olfaction and why explanations that link odor perception to molecular structure inevitably fall short.

The empirical characteristics of the olfactory system also illustrate why traditional neglect and dismissal of the sense of smell rested on misconceptions. On the one hand, we saw that smell is not subjective in the sense mentioned earlier. Olfactory variations can be explained causally by appeal to the biology, cultural context and personal history of an individual, in relation to an odor stimulus rather than due to purely idiosyncratic internal configurations. Olfaction thus is remarkably flexible and adaptable to an organism's environment, its physiological constitution and its needs. It is also remarkably precise in detecting minute chemical features and differences. Consider hexyl acetate ($C_8H_{16}O_2$), which smells of banana. If you add one carbon atom (plus two hydrogen atoms), you get heptyl acetate ($C_9H_{18}O_2$) that smells of pear. Our common sense understanding of the sense of smell usually underestimates our discriminatory abilities (Young, 2020), and it takes empirical investigation to reveal the range and precision of human olfaction putting traditional philosophical notions of perception to the test.

Introspective methods, or meta-cognition about our "everyday" perceptions, do not suffice to tell us about the reach and accuracy of these perceptual experiences or how they relate us to the world. We need to augment our examination of the human sense of smell by adding what we learn from the neurobiology and psychology of olfaction. Some philosophers resist this recent trend of turning to science to inform our answers to philosophical problems. For example, Louise Richardson (2013, p. 333) cautions that: "(…) if one wants to argue that some finding [from the sciences] corrects our everyday conception, one must demonstrate not only that the finding contradicts something that people think: one must also provide reason for believing that their thinking is central to the everyday conception of the senses." Lucky for us, it is possible to oblige here. An excellent case in point is the role of olfaction in what we ordinarily call 'tasting.'

Richardson (2013), for example, denies that smell plays a part in perceiving flavors in everyday experience. From a physiological standpoint, however, we know that flavor perception is a multimodal experience that involves smell, taste, and touch (temperature, texture, chemesthesis), and can be influenced by audition and vision (Shepherd, 2012; Smith, 2012, 2020; Spence et al., 2015). Olfaction plays a constitutive role in flavor perception. When we experience the flavor of strawberry or mint, it is worth noting that we do not have strawberry or mint receptors on our tongue. All our tongue can provide us with are the tastes of sweet, sour, salt, bitter, and umami, while our sensory access to flavor qualities like strawberry or mint is due to retronasal olfaction. Retronasal smelling involves the release of aromatic molecules during chewing, which then travel via an opening of the back of the throat (the pharynx) to the nasal epithelium. While we experience the flavor of strawberry in the mouth, the real action happens in the nasal epithelium. This gives rise to a location illusion where the flavor qualities detected by the nose are experienced as if they were happening on the tongue: this phenomenon is known as "oral referral" (Spence, 2016). These physiological facts about flavor perception are not revealed to us by mere reflection on our everyday experiences of perceiving flavors in our foods. In fact, olfaction appears to go missing when we reflect on our everyday experiences of 'tasting'. We think we taste flavors with the tongue, and although retronasal olfaction makes a decisive contribution to flavor experiences, what it contributes is not recognized, introspectively, as being olfactory. Instead, the perceptions resulting from the multisensory integration of inputs from taste and smell that produce flavor experiences are mistakenly classified as experiences of taste alone.

We lack transparent access to the senses involved in our experiences of flavor. But this does not preclude access to the sensory components. We can uncover the distinct contributions of smell and taste utilizing a simple experiment in which people can come to experience for themselves how little of the flavors of our foods the tongue can give us. When people put a nose clip on and eat a piece of fruit, all they can detect is whether something is sweet, sour, or bitter. Then, when they remove the nose clip while chewing, they are struck by how smell rushes in to add a flavor dimension to the somewhat muted experience that the 'pure' basic tastes provide. People are surprised but readily update their understanding after learning just how much of what they call "tasting" is due to their sense of smell.

Richardson (2013) accepts that the knowledge gained through such experiences, and therefore the science behind flavor perception, contradicts what people commonly think about detecting all these flavors with their tongues. Still, she *denies* the idea that thinking we taste flavor with the tongue is "central to the everyday conception of the senses." This description of Richardson's account may sound paradoxical, even to ordinary perceivers, so let us unpack her reasoning: Richardson denies that odor molecules traveling to the epithelium via the mouth (not the nose) to the nasal epithelium—which gives rise to the most significant part of what we call tasting—is genuinely part of smell. Her alternative view amounts to a philosophical speculation about science. Neurobiology tells us that smell and flavor share (i) the same distal stimulus (odorants), (ii) the same sensory receptors in the nose, and (iii) where flavor can be revealed as in part olfactory in our sensory experiment above. But, according to Richardson, what we *think* about odorants reaching the nose is not '"central to the everyday conception" of the sense of smell. In turn, our everyday conception of tasting need not involve thinking we taste with our tongue, and, by parity, the everyday conception of smelling need not involve people thinking our nose does the smelling. This framing leaves Richardson free to admit that the nose and the tongue are both causally involved in producing "everyday experiences of tasting" and that, at the physiological level, the nose serves to implement both "everyday experiences" of tasting and "everyday experiences" of smelling. But now, contrary to the science of flavor and contrary to what the folk thinks once they've experienced the nose clip test, Richardson wants to insist that smelling (in the "everyday" sense) is not involved in tasting (as in: the phenomenal experience of) flavors.

When dismissing appeals to what the nose does and what the tongue does in this conception of smelling and tasting, we are left to wonder how "everyday" this underlying conception of the senses really is. Besides, if ordinary people do not share this notion of these senses (as part of how they ordinarily think about their senses), and further don't resist the scientific explanation (of their own revelatory experience in the nose clip experiment), it remains unclear what the ultimate point is of carving out such an artificial philosophical conception of taste and smell - or if it is only to resist the science of olfaction, gustation, and flavor. Richardson asks why scientists should be allowed to dictate to people what taste is. But equally we could ask why philosophers are any more entitled to do so when both depart from ordinary experience.

Vivien Mizrahi is another philosopher of olfaction who worried about letting scientific approaches to smell and taste correct ordinary ways of thinking about them. The worry is partly methodological. Why should philosophers concede that scientists have matters right "as if some corrections were needed to make people aware of the true nature of perceptual experience" (2013, 3)? The true nature of perceptual experience is supposed to be transparently revealed to us by reflection. However, the nose clip test precisely does help to make people aware of the underlying complexity of their perceptual experience of tasting. Milliseconds after the nose clip is removed, people feel the contribution of smell rushing in to restore the full awareness of flavor. Once taste and smell are united, people find that it is no longer possible to parse their experience into the separate contributions of taste and smell. Once more, it feels as if they are detecting all the flavors with the tongue, but moments before, they knew how little the tongue was providing. So now they realize, with respect to taste and smell, "the true nature of [their] perceptual experience." The trouble occurs because Mizrahi trusts her philosophical intuitions about tasting flavors with the tongue as a guide to the true nature of what is going on with our senses and fails to distinguish gustation (taste proper) from the ordinary use of the word 'taste' (ie. flavour), which refers to experiences produced by gustation and retronasal olfaction. By confusing taste and flavour, something Spence et al. (2015) go to great lengths to avoid, Mizrahi in her reply to them

is unable to show that flavour experiences are just a matter of taste. Our appeal to sensory science and experiments connected with a broader understanding of people's ordinary taste (flavor) experiences and what gives rise to them provides the needed correction. The trouble with taking what is familiar about our perceptual experience as an inevitable guide to its nature is twofold. On the one hand, we miss vital facts illuminating the "true nature of perceptual experience." On the other hand, we conflate our personal and limited philosophical intuitions with how people can think more broadly about their "ordinary" experiences when they undergo a sensory test.

Beyond disputes about philosophical methodology and intuitions, why should empirical insight into the sensory pathways that affect ordinary perceptual judgments about food aromas and flavors count as part of the elucidation of those perceptual experiences?

Part of the answer is that knowledge of the sensory pathways helps to explain what goes wrong when people with upper respiratory viral infections, who have lost their sense of smell, declare that they cannot taste the food they are eating. In 2020, when the SARs-CoV2 virus led to worldwide outbreaks of Covid-19, around 65% of those diagnosed as having Covid suffered from olfactory dysfunction, including the sudden onset of anosmia (smell-loss), hyposmia (reduced smell), and parosmia (smell distortion). Across the world, people reported being unable to appreciate food and could not even discern the taste of one fruit from another. Although a small percentage of patients suffered a loss of taste, the vast majority of Covid sufferers were subject to smell loss. At first, even medical practitioners neglected the relevance of smell to people's inability to “taste” foods; many have also failed to acknowledge the profound effect the sudden loss of smell has on people's perception of their surroundings and of themselves. Many of those suffering from anosmia speak about feeling as if they are experiencing the world behind glass. Many report symptoms of loss and anxiety and speak of feeling alienated from their own homes (Burgess-Watson et al., 2021). These experiences reveal to their subjects the previously unappreciated extent to which smell contributes as an unappreciated but ineliminable dimension of “everyday” perceptual experience. Accordingly, we must augment reference to ordinary perception with scientific insights on the senses to appreciate how senses, like the sense of smell, matter in ordinary people's lives and create their everyday and pathological experiences.

In addition to the practical impact, there is a question of how much of ordinary perception is knowable on the basis of reflection, as discussed in Section 2. Phenomenological accounts of inner experience are not a *naïve* guide to the given nature of smell. Sensory perception can be honed and improved, and we learn how to go in for *trained* introspection (Churchland, 2013). It thus is often a matter of meta-cognitive judgment, which has shown notoriously unreliable when assessing our olfactory abilities. Furthermore, there can be variations in how we classify sensory modalities across cultures and throughout history. A case in point is the often-cited status of the five senses proposed by Aristotle, which we also find referenced in Richardson (2013). However, the historical consolidation of the five senses was not grounded in people's appreciation of their ordinary perceptions but religious symbolism. Indeed, non-canonical thinkers divided and studied the senses differently in history (Kaufmann, 1884). Furthermore, cross-cultural perspectives complement and extend our theories of the senses, including how many there are and how they overlap (Classen, 1997).

Philosophical engagement with olfactory science helps to spotlight characteristics of odor perception not visible in introspective and phenomenological accounts. In this context, the scientific details are relevant to a scientific and philosophical understanding of olfaction.

As philosophers of perception, the further question we must engage with is what the discrepancies between our ordinary perceptual experience and the scientific insights into it tell us about the nature of perception, our knowledge of it, and to what it gives us access. Thus, a fully adequate philosophical study of olfaction must begin where this article ends: at the juncture between pre-scientific beliefs about the nature of perception and empirical insights into its causal dynamics.

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ENDNOTES

[1] Recent work broadening philosophical theories of perception includes audition (O'Callaghan, 2008), interoception (Garfinkel, 2019), proprioception (Ritchie & Carruthers, 2015), touch (Fulkerson, 2014), taste and tasting (Smith, 2007), and synesthesia (Deroy, 2017).

[2] We thank Eduard Machery for urging us to clarify this point.

[3] Further arguments on this issue by Barwich (2019, 2020).

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