The Temporal Structure of Olfactory Experience

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Abstract

Visual experience is often characterised as being essentially spatial, and auditory experience essentially temporal. But this contrast, which is based upon the temporal structure of the objects of sensory experience rather than the experiences to which they give rise, is somewhat superficial. By carefully examining the various sources of temporality in the chemical senses we can more clearly identify the temporal profile of the resulting smell and taste (aka flavour) experiences. This in turn suggests that at least some of the objects of olfactory experience have significant temporal structure, including interactions between odorants and the body's own sensory systems. This can help to inform our understanding not only of the metaphysics of olfaction, but the temporal structure of sensory processing and experience in other sense-modalities, including vision and audition.

Keywords: taste; smell; olfaction; flavour; temporal perception; sensory integration; metaphysics of experience

Now I've heard there was a secret chord
that David played, and it pleased the Lord,
but you don't really care for music, do you?
—'Hallelujah', Leonard Cohen

1. Introduction

Vision is often held to be paradigmatically spatial, and audition paradigmatically temporal. Such is the received view of the 'higher' senses. The 'lower' senses of touch, taste and smell, on the other hand—not to mention bodily senses such as balance, proprioception, and kinaesthesia—are typically held to be exclusively spatial to varying degrees, if at all. While this view suggests an appealing symmetry between vision and audition, it is also misleading, along with the division between 'higher' and 'lower' senses upon which it is premised. *All* of our senses are temporal insofar as they afford us experience of the world as it is 'now', i.e. roughly contemporaneous with experience, and as it changes over time. Arguably, though I won't pursue the point here,[1] all of our senses are also spatial at least insofar as they afford us experiences of how things are 'here', where the perceiver is located,[2] or in the case of exteroception *from here*, where the perceiver's relation to the objects and properties perceived affects the phenomenal character of the resulting experience. The alleged contrast between vision and audition is thus somewhat superficial, being based on a contrast between the characteristic objects of these senses, which persist in different ways (§2). All of which brings us to olfaction and gustation.

The paradigmatic cases of olfactory or gustatory experience typically described by philosophers, such as smelling the scent of a rose or tasting coffee, for example, tend to emphasise the role of perceptual categorisation. That is, recognising the *kind* of thing—rose, coffee, etc.—that one is smelling or tasting. But this seemingly straightforward

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[1] See Aasen (2019), Cheng, Deroy & Spence (2019), Young (2020), and Wilson (in press).

[2] Batty (this volume).

perceptual achievement masks a host of complexity, both in terms of how one recognises odours of different types, and in the temporal structure of smelling and tasting themselves. Indeed, most of our olfactory experience is arguably not of this kind, but rather signals the presence of variations in the olfactory environment where the identities of the relevant odours are unknown, or their sources unclear. We should therefore distinguish between (1) the mere *detection* of an odour, (2) its *recognition* as a familiar, but as yet unidentified smell, and (3) the *identification* of an odour or odour source as falling under some perceptual category or description: strawberry, Merlot, metallic, etc. The onset of each of these states is punctate, and they often occur at different times. The character of the underlying olfactory experience, however, typically varies over time, as different aspects, or 'notes', of the odour become successively apparent at varying concentrations—or so I will argue (§3). This makes smelling (and derivatively tasting) a complex dynamical process in which a series of interactions facilitate recognition of olfactory patterns over time, rather than a binary state.[3]

In this chapter I examine the various sources of temporal structure in olfaction and gustation, ranging from purely mechanical aspects of the respiratory and gustatory systems—breathing, sniffing, chewing, swallowing—to the mechanisms of olfactory detection, and the integration of multiple sensory channels (§2). I then consider the temporal character of the resulting experiences of smelling and tasting (which I take to be a partly olfactory experience), and their function in monitoring the continually changing olfactory environment (§3). This in turn motivates the claim that at least some objects of olfaction have significant temporal structure, including interactions between odorants or tastants and the biological mechanisms for their detection. This need not, however, render smelling or tasting subjective in any philosophically important sense, but rather highlights the perspectival nature of these experiences (§4). Finally, I argue

[3] For the idea of olfaction as a form of pattern recognition, see Barwich (2020), chs. 6 & 8. On the importance of diachronic olfactory experience, see Young (2015, 2020, this volume).

that similar temporal features are present in non-chemical senses whose temporal structure—with the exception of audition—is similarly often ignored. Careful consideration of the temporally extended nature of olfaction and the experiences of smelling and tasting to which it gives rise can thus gives insight into the fine-grained temporal structure of sensory experience in general.

2. Sources of Temporal Structure in Olfaction

It is uncontroversial that sensory experience, indeed *all* experience, is temporally extended. After all, we use our senses to discover and explore the world in a dynamical cycle of perception, attention, and action. The contrast between vision and audition noted above with respect to time is thus not a contrast between the temporal extension of visual and auditory *experiences*, since both are extended, but a contrast between the *objects* of those experiences. The objects of vision are characteristically spatial and may be thought of as persisting by *enduring*. That is, they are fully present at every moment they exist, and, time lags notwithstanding, when they are experienced. The objects of audition—for example, sounds[4]—are ostensibly a kind of event, and so characteristically persist in virtue of having non-identical temporal parts. That is, they *perdure*.[5] Consequently, we cannot say that we have heard the whole of a word or a symphony unless we have heard all of its parts. So while both visual and auditory experience are temporal, and arguably also spatial (Wilson, in press), the objects of audition, at least at first blush, extend over time in a different manner to the objects of vision.

The above broad-brush characterisation of vision and audition raises various questions with respect to the chemical senses of smell and taste. First, to what extent does the temporal structure of olfactory experiences contribute to their distinctive phenomenology and function? This in turn depends on precisely what we take their

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[4] I leave it open what the correct account of auditory objects is (cf. Casati & Dokic 2014).

[5] On the distinction between endurance and perdurance, see Hawley (2020).

function, or functions, to be. I argue in §3 that this goes beyond merely recognising or identifying odour-types—smelling coffee, or a rose—to monitoring the dynamically changing qualities of the olfactory environment, and so has a distinctive temporal structure. Second, do the objects of smell and taste experience persist in a similar manner to visual or auditory objects? This depends on what we take those objects to be. The answer to this question remains controversial among philosophers of olfaction (including many of the contributors to this volume), with options including molecular structures, odour plumes, smellscapes, stuffs, olfactory and physico-chemical properties.[6] While I will remain neutral on this issue, I argue that these should be extended to include temporally extended objects or events such as variations in odour mixtures, concentration gradients, and interactions between odorants and sensory systems (§4).

Rather than starting by introspecting olfactory phenomenology, which is notoriously difficult to describe or report, I begin by surveying the various sources of temporal variation of olfaction and gustation. These may usefully be grouped into five categories: those that occur in the olfactory environment (§2.1), in the nose and mouth (§2.2), at the receptors (§2.3), in the brain (§2.4), and in sensory integration (§2.5). For brevity I will focus mainly upon olfaction, i.e. sensing via the nose, though similar points apply to gustation, i.e. sensing via the tongue. In the following section, I examine how these affect what we normally call 'smell', i.e. orthonasal olfaction plus trigeminal activity, and 'taste'—or more properly *flavour experience*—of which olfaction forms a substantive part.[7] In each case, I will argue that the various temporal features

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[6] See Lycan (2014), Batty (2014), Mizrahi (2013), Richardson (2018), and Young (2019, 2020) for discussion. For simplicity, I will ignore accounts that take chemical senses to be purely sensational or stimulus–response mechanisms; e.g. Burge (2010: 415).

[7] I take olfaction, gustation and the trigeminal system to be physiological *sensory channels*, as opposed to 'smell' and 'taste', as ordinarily conceived, which are psychological or *experiential modalities*. However, nothing below turns upon this terminological point (cf. Wilson 2021). For further discussion of the relation between smelling and tasting, see Auvray & Spence (2008), Richardson (2013), Spence, Auvray & Smith (2014), Smith (2015), and Wilson (*ibid.*).

identified below constitutively affect the structure of the resulting olfactory experiences, and so we should consider the temporal dimension of smelling and tasting to be of metaphysical significance (§4).

2.1. Temporal Variation in the Olfactory Environment

Olfaction involves the detection of *odorants*: the chemical substances or compounds to which our olfactory receptors are sensitive. These may be distinguished from *odour sources*, which produce or emit odorants. In some cases odorants and their source may be of the same kind or type. In general, however, odorants are the volatile subparts of their sources to which we are olfactorily sensitive. As the proximal objects of olfaction, odorants are perceptual intermediaries, with their distal sources being perceived only indirectly by means of the odorants they emit. This contrasts with vision whose intermediary—light—we generally take to be an enabling condition for visual experiences of distal physical objects, and rarely an object of visual experience in its own right except in special cases.

Bracketing whether we have olfactory experience of distal sources as distinct from or in addition to the odorants that they emit (see Aasen 2019), odorants may vary in their relative concentrations, whether they are simple (i.e. single-molecule) or complex (i.e. multi-molecule), and other physico-chemical properties; e.g. molecular weight, temperature, handedness, and so on. For simplicity I will speak of an odorant as a single compound or chemical substance. However, many of the odours that we experience are a result of mixtures of such compounds. Varying the concentration or ratio of individual odorants thus affects the perceived qualities of the resulting odour.

Though the paradigm case of olfaction is standardly taken to be a single odour-type smelled at close range—e.g. sniffing a rose—in everyday experience we more typically encounter mixtures of odours arising from multiple distal sources. Walking through the supermarket, for example, I can smell the odour of freshly baked bread (circulated through the store to make me feel hungry and buy more fresh produce), the perfume and body odours of my fellow customers, the scent of cleaning products or detergent in the aisle around me, and so on. Young (2020) has elsewhere called this kind of ecologically typical mixture of odorants a *smellscape*. I will later argue that it is part of the function of olfaction to identify changes in the precise mixture of odorants that are detected, and so monitor variations in the surrounding olfactory environment over time. But whether the direct objects of olfaction are taken to be odorant mixtures, smellscapes, molecule clouds, or "stuffs" (Mizrahi 2013), the physical nature of odorants permits of a considerable range and number of dimensions of variation.

First, and most obviously, there can be the appearance or disappearance of an odorant or mixture. This may happen suddenly or gradually, crossing the threshold of detectability (which differs between odorants), and signalling the presence or absence of the corresponding odour or odour source. Second, there can be variations in odorant concentration. This may occur for a variety of reasons, including changes in proximity to the odour source, the quantity of odorant emitted, and local variations in distribution due to air currents, variations in mixing, and so on. A special case of such a variation is that of a *concentration gradient* where the concentration of an odorant or mixture varies proportionately to the subject's proximity to its source. This enables the gradient to be followed using a combination of successive sampling, e.g. sniffing, over time and movement in order to locate the source, or to avoid the odour (Young, Escalon & Mathew 2020). Spatial variations in odorant concentration may therefore be detected over time either because the odour is moving through space, or because the subject is.

Finally, odorants themselves can change due to reactions with other environmental factors or conditions, such as heat and humidity. Many odorants are highly volatile chemicals and so readily react with other olfactory or non-olfactory compounds—something that becomes important when we consider their passage through the warm and humid environment of the nose or mouth (§2.2). Physical changes in odorants can also create discernible variations in the character of the resulting experience, enabling the age or freshness of an odour or foodstuff to be perceived (cf. §3).

2.2. Temporal Variation in the Nose and Mouth

Each of the above variations involves some physical change in the olfactory environment external to the body. In order to detect odorants, however, they must be taken into the body, which occurs via one of two pathways. Firstly, and most obviously, by inhaling odorants through the nose by breathing or sniffing. This is *orthonasal olfaction*, or 'smelling' as we normally think of it. Secondly, odorants may be exhaled from the back of the mouth or throat in *retronasal olfaction*. This typically occurs when eating and drinking and, in conjunction with gustation and somatosensation, is a major component of what we standardly call 'taste', and philosophers call 'flavour' (cf. Spence, Auvray & Smith 2014). Regardless which route odorants arrive by, however, they end up in the nasal cavity where they are detected by the *olfactory epithelium*, the sensory surface for olfaction. The precise pattern, timing, and intensity of the resulting stimulation, however, may differ (Wilson 2021).

Importantly, odorants are not delivered not as a steady stream, but in distinct pulses or bursts. In orthonasal olfaction, these correspond to the rhythm of breathing or the action of sniffing, both of which may occur in short or long bursts—for example when deeply inhaling the scent of a pine forest. In retronasal olfaction, this is a consequence of the mechanical activity of chewing and swallowing. These mechanical actions are significant because they give the delivery of odorants to the epithelium a distinctive temporal pattern or rhythm. With the possible exception of gustation, which is linked to the act of chewing, no other sense-modality is structured in this way over similar timescales. This makes the temporal structure of olfaction somewhat dissociated from that of other sense-modalities, with a delay of up to a second before odorants are consciously detected, and even longer before their qualities and valence are registered (Olofsson 2014). Indeed, in part due to the varying lengths of time that it takes odorants to reach the epithelium from their sources, we often smell objects well after, or well before, we see them. The brain thus has to figure out which smells are associated with which source objects—something that is often not apparent upon the basis of timing or spatial location alone.

The action of sniffing thus plays an important role. By taking a deliberate and targeted olfactory sample of the surrounding environment, it enables the subject to control the amount of odorant admitted into the body, and so the intensity of the resulting experience. Moreover, by taking in more air, and thus a greater quantity of odorants, it also enables detection of stimuli that may otherwise fall below threshold. Positioning the nose close to some actual or potential odour source can thus facilitate fine-grained identification or disambiguation of odour sources. By varying the rate and depth of sniffing, the pattern and intensity of odorant pulses can also be controlled—whether consciously or consciously. According to Young (2020: 209), "[w]ithin 150–300 ms of stimulus presentation, sniffing is modulated in accordance with the concentration, intensity, and valence of the odorant". That is over half a second *before* this information is consciously registered. Conversely, we can breathe less deeply, or cover or pinch the nostrils shut altogether to block out unpleasant or unwanted odours, including the olfactory component of flavour.

Much the same occurs with taste. By varying the quantity of food or drink taken into the mouth and how quickly it is chewed and swallowed, we can vary the duration and intensity of the resulting gustatory and olfactory stimulation. This results in odorants being delivered to the olfactory epithelium in pulses corresponding to the bursts of volatile compounds emitted while chewing and swallowing. Thus food can be consciously savoured for pleasure, or hastily disposed of, as when swallowing an unpleasant-tasting medicine. Gustation, however, is not divided into pulses in this way as the taste receptors on the tongue continuously detect tastants in the mouth. As in olfaction, however, there is variation in the precise set of receptors that are stimulated at any given time due to the movement of tastants around the mouth—a process that also generates somatosensory and sometimes auditory stimuli. Along with olfactory and trigeminal signals, these are integrated to form the resulting flavour experience, which is a composite of multiple sensory channels (§2.5).[8]

As noted above, odorants interact may react both with each other and with the environment of the nose or mouth. This is particularly the case during eating and drinking, where foodstuffs are pulverised and mixed in the mouth, combining with saliva, causing volatile chemicals of different types and concentrations to enter the nasal cavity. Warming or cooling of odorants along with their interaction with the moist environment of the body can also result in variations in the combination of odorants that reach the nasal cavity over time. Even a constant mixture of odorants in fixed proportion can cause a long and complex chain of chemical reactions as odorants interact both with each other and with the nasal mucosa. Thus there can be temporal variation even where the stimulus itself undergoes little or no change independently of the body. Rather, the process of the olfactory system assimilating odorous compounds is itself a source of temporal variation.

2.3. Temporal Variation at the Receptors

Once odorants reach the olfactory epithelium, they are absorbed by the nasal mucosa, the moist lining of the epithelium where they are detected by the olfactory receptors. These are specialised nerve cells that are directly exposed to the incoming airflow, protected only by the mucosa. Consequently, the lifespan of olfactory receptors is relatively short, though new receptors are constantly being generated. The epithelium contains approximately four hundred out of a possible six hundred distinct receptor types, with the precise mixture of receptors depending upon the subject's genetic makeup and individual history since receptors that are stimulated tend to regenerate

[8] Though it is controversial precisely which sensory channels are constitutive of flavour experience and which merely causally affect it, I take it that at least gustation, olfaction and trigeminal stimulation fall into the former category. See Spence, Auvray & Smith (2014) and Smith (2015, 2020) for discussion.

more readily, whereas those that are stimulated less die off and are not replaced in equal number. This gives rise to a degree of variation in the olfactory compounds that can be detected by a given individual, though there is also a large degree of overlap.

The process of detection itself imposes a distinctive temporal signature. First, not all odorants reach the epithelium at once or are detected simultaneously. Different odorants take differing amounts of time to reach the olfactory epithelium, depending upon their weight, and to bind with and/or inhibit different receptor types (see below). Crucially, many odorants can bind to several different receptor types, sometimes in multiple ways. Thus the mapping between odorants and receptor types is not one-to-one, but many-to-many. With typical odours consisting of dozens to hundreds of such compounds, this gives rise to a complex pattern of stimulation that must be detected and decoded in order to identify a given odour type (§2.4).

This complexity is further increased by the fact that not only can odorants stimulate, but they can also inhibit various receptor-types (Barwich 2020: 187). This becomes important when detecting odorant mixtures because the same chemical compounds both activate some receptors while inhibiting the activity of others by physically blocking them for activation by other odorants. Odorants physically bind to receptor sites, so blocking or activating receptors prevents them from accepting further odorants until they are cleared by chemical processes occurring within the mucosa. Odorants can thus persist in the epithelium for anywhere between a few seconds to several minutes or longer. The detection of odours is thus not simply additive in the sense of involving the particular combination of odorant-types that detected at a given time, i.e. synchronically, but depends upon the precise mixture of odorants as they interact with receptors over an extended period of time, i.e. diachronically.

The resulting pattern of activation and inhibition may be further modified by the activity of *allosteric channels*.[9] These act as a 'side-channel' or gate to olfactory receptor cells, enhancing or inhibiting their activity in the presence of yet further compounds

[9] I thank John Behan for bringing these effects to my attention.

that may or may not be directly detectible by olfactory receptors. Some such compounds—alcohols, for example—appear to act as odour enhancers, increasing or inhibiting receptor activity without themselves being independently perceivable, and so may be almost or entirely odourless (*ibid.* 193). Nevertheless, this can boost an associated odorant above the detection threshold, or negate its effects entirely, adding further complexity to the detection of odour mixtures. In other cases, allosteric compounds may enhance the activity of one receptor type while directly activating or inhibiting other olfactory receptors, with each of these effects occurring on different timescales.

Inhibition and enhancement effects also help to explain why an individual odorant might not be recognisable as a distinct component, or 'note', of every odour mixture of which it is a part. Instead, its effect will depend upon the context and order in which it is detected. As a consequence, it is the odorant mixture as a whole, or olfactory *gestalt*, that is detected rather than the sum of its individual parts. These effects also have distinctive temporal characteristics since odorant binding and inhibition does not take place all at once, but as part of a complex interplay between multiple odorants and receptor types that unfolds over multiple seconds. Different odorants take different amounts of time to reach the olfactory epithelium, and to bind with or inhibit various receptor types. Consequently, activations of certain receptor types may peak before being damped down or enhanced by other odorants, or via the activity of allosteric channels. Unlike in vision or audition, then, where all frequencies of light or sound arrive together, even the detection of a single odour may have a complex temporal structure that is like the unfolding of a complex melody or chord in which each 'note' signals the activation of one or more receptor-types.

The analogy of a melody composed of distinct notes is a familiar one in relation to olfaction. But whereas perfumers or wine connoisseurs often speak of olfactory or flavour 'notes' as odoriferous qualities, which may or may not be present at once, here I mean a succession of distinct events over time. Deroy (2007) similarly appeals to the metaphor of a "musical line" for the experience of wine-tasting, though finds this less plausible in the case of ordinary olfaction, where the main dimension of variation is in intensity. Nevertheless, whenever odorant mixtures are present, and sometimes even when they are not, this generates a complex interplay between the activation and inhibition of olfactory receptors over time. Given the presence of multiple concurrent and consecutive elements, a better auditory analogy might be that of a complex and constantly shifting chord in which new 'notes' or harmonics appear and disappear over sub- to multi-second timescales. The 'shape' of this chord is part of what gives each odour or mixture its distinctive temporal as well as qualitative signature in a way that may, though need not, show up in olfactory experience (§3).

Given the temporally extended, dynamic, and not straightforwardly additive nature of receptor activity, it makes sense to think of odour detection not as providing a series of snapshots of what is entering or inside the nose, but a complex dynamical interaction that plays out at the receptor level. Nor does this process cease as soon as an odour is detected or identified, since the olfactory system continues to monitor the changing olfactory environment in order to detect variations in concentration, and the presence or absence of new odorants over time, clearing the epithelium of previously detected odours, and suppressing their effects in favour of newly detected changes.

2.4. Temporal Variation in the Brain

The activation of olfactory receptors is just the first stage in a chain of neural activity that extends from the olfactory epithelium through the olfactory bulb, pyriform cortex, orbitofrontal cortex, and into higher brain areas. In contrast to our relatively advanced scientific understanding of the visual and auditory cortices, however, the grouping and decoding of patterns of olfactory receptor activations into something that corresponds to what we call 'odours' is not yet well understood. I will therefore comment on just two features of this process that are of particular significance for the temporal structure of olfaction.

The first concerns the activity of olfactory neurons, and indeed populations of neurons more generally. These do not function solely on an individual basis, but become entrained in waves of co-activations that enable synchronisation between different, sometimes spatially disparate, brain regions. The resulting cycles of activation and inhibition take place over significant periods of objective time, lasting tens or hundreds of microseconds per oscillation, giving olfactory signalling a fine-grained rhythmic dimension. This kind of population coding forms part of a temporally extended signalling system that enables a dominant signal to emerge from an otherwise complex and noisy environment. Neurons that are in sync with the dominant cycle help to reinforce and stabilise it over extended periods of time. Those that are out of sync constrain and may ultimately disrupt it, creating a new synchronised oscillation when the input signal changes sufficiently, or in response to top-down modulation.

The second feature concerns the role of top-down influences in the olfactory system. Once a pattern of synchronisation has been established and stabilised, it may be sustained by high-level predictions of what is current being, or about to be, detected. This is most obvious in the case of ambiguous odours, such as benzaldehyde, which can smell like almond or cherry depending on contextual factors, and dihydromyrcenol, which smells either woody or citrusy depending upon what has been smelled previously (Martina 2021). These factors interact with the kind of periodic oscillations described above, shifting them into new stable patterns that affect the subjective character of the resulting olfactory experience. This can result in a flip-flopping of experience between two different perceived qualities, despite the stimulus remaining unchanged.[10] Instead, the equilibrium in the brain is perturbed by a change

[10] Herz and von Clef (2001: 384–87) also found that when presented with the same mixture of isovaleric and butyric acid, subjects gave different pleasantness ratings depending on whether it is labelled as ‘parmesan’ or ‘vomit’. However, judgements of valence may depend upon slightly different mechanisms.

in top-down expectations prompted by a shift in attention, or by non-olfactory stimuli, such as a changing visual image, or noise in the system.

Even when smelling a single non-ambiguous odour, however, it is likely that top-down modulation plays a role in establishing and stabilising patterns of neuronal activity. This may be why we typically do not notice continuous variations in olfactory stimuli until they become highly salient—a dramatic change in the environment, for example—or violate our prior expectations or predictions about what it is we are smelling. Hence subjects can be easily fooled by countervailing evidence, such as when a familiar food or drink is presented in an unusual colour, altering its perceived flavour (Spence 2015).

Crucially, however, each of these olfactory mechanisms appears to be designed to detect environmental changes. Habituation is both relatively rapid and extremely prevalent, even at relatively high levels of concentration, and not limited to the receptor level as in the case of visual accommodation, for example. Rather, at every level the olfactory system seems to be tuned to detect changes in olfactory stimuli over time, rather than continuing to generate conscious experience of unchanging stimuli. This gives us some clue as to the function of olfaction, along with its temporal metaphysics, as discussed below.

2.5. Temporal Variation in Sensory Integration

Olfaction and gustation do not exist in splendid isolation. As described above, they are causally influenced by and, in the case of flavour experience, constitutively related to other sensory channels and modalities. As Smith (2015: 330) points out, both flavour and smell are arguably multimodal in that they include both olfactory and trigeminal components, plus much more besides in the case of flavour. In order for these distinct components to be experienced as a unified whole, they need to be bound or *integrated*, which also takes place over a distinctive timescale. We know from studies of other modalities, that inter-sensory binding occurs in the 75–125 ms range (Vroomen &

Keetels 2010: 874). This is longer than the neural oscillations described above and shorter than the rhythm of the breath, but still easily within the consciously discernible range. (For comparison, auditory stimuli as little as 10–12 ms apart may be experienced as discrete events, though the temporal resolution of vision is somewhat lower than this.) Moreover, this figure appears to be relatively constant across the senses, suggesting the existence of a common mechanism, possibly linked to the brain's alpha rhythm, which runs at approximately 10 Hz (Cecere *et al.* 2015). Alternatively, olfaction and gustation may be more tightly bound due to their common role in flavour perception, and so exhibit their own temporal window.[11] However, binding with other stimuli in other modalities seems to use a common mechanism.

Inter-sensory binding can alter the perceived timing of events across modalities. An auditory stimulus occurring up to 100 ms before or after a visual stimulus, for example, causes the latter to be perceived as 5 ms earlier or later than it really is (Vroomen & de Gelder 2004; Chen & Vroomen 2013). Moreover, in order for olfactory and gustatory stimuli to be experienced as a unified flavour experience, they must fall within a limited temporal window. By varying the relative timing of olfaction and gustation, Stevenson, Oaten and Mahmut (2011), following von Békésy (1964), were able to control whether olfactory stimuli were perceived as located in the nose or throat —an effect known as *gustatory referral*. The precise timing of these signals thus dictates whether they are experienced as distinct orthonasal and gustatory experiences, or a unified flavour experience. Hence the temporal structure of olfactory and gustatory processing makes a constitutive difference to which sensory modality is experienced. This leads us from the realm of sub-personal activity in the olfactory and gustatory systems to first-person olfactory experience, or 'smell' and 'taste' as we normally think of it.

[11] For further discussion of the notion of a temporal window, see Wilson (2022).

3. Olfactory Experience

Having examined various factors in the external environment, sense-organs, and nervous system that shape the temporal profile of olfaction, how, if at all, are these factors manifested at the level of conscious experience?

The first thing to note is that much of our olfactory experience goes unnoticed, which is to say that it is not consciously attended (Smith, this volume). This is perhaps in part due to the fact that many of us now live in largely sanitised and relatively odourless environments. However, the dominance of visual perception is such that it is only when we encounter a new, strong, or highly valenced ('good' or 'bad') odour, or engage in deliberate olfactory exploration such as sniffing or eating that olfaction typically comes to the forefront of our overall experience. However, that is not to say that it makes little or no difference to the character of everyday perceptual experience.

People who suffer from smell loss, i.e. *anosmia*—a condition that has unfortunately recently become more common due to the SARS-CoV-2 virus, of which it is a characteristic symptom—find it significant impacts not only their experience of food and drink, but much of their daily lives (cf. Tafalla 2013). In particular, anosmics miss the familiar odours of people, places, everyday objects, and environments, sometimes leading to emotional problems such as depression or a sense of alienation and derealisation. This demonstrates that olfaction not only provides us with useful information about the things we deliberately smell or ingest, but forms an important part of our everyday engagement with the world. In particular, it provides a sense of *immersion* in the surrounding environment. So while olfaction often remains in the background of experience, it nevertheless makes a significant and ongoing contribution to its phenomenal character and, through it, our general sense of wellbeing.

The second thing to note is that we must be careful not to characterise smell and taste experiences purely in terms of odour identification and recognition. While this forms a part of our overall experience and contributes to top-down modulation (§2.4), these are best described as epistemic achievements made *on the basis of* olfactory experience, rather than being constitutive of it. They mark the onset of cognitive states, such as smelling or tasting that something is in the environment, rather that capturing the succession of odour qualities that are present in experience. We can mark this as a distinction between *smelling*- or *tasting-that*, which is an epistemic or cognitive state, and *simple smelling*, which is a purely perceptual experience, and so processive (cf. Dretske 1979). Notably, the former may occur, if at all, some period time after the latter. Indeed, it is often surprisingly difficult to label or identify an odour source without further non-olfactory, e.g. visual or auditory, cues. This gives rise to the familiar 'tip of the nose' effect in which an odour is recognised, but cannot yet be identified or labelled. To accurately characterise simple smelling, or olfactory experience itself, then, we need to consider what happens *before* an odour is identified or labelled.

Far from being snapshot-like, smelling and tasting are highly dynamic processes that reflect the temporal characteristics of the underlying sensory systems. Indeed, now that we know what to look for, it is possible to discern many of the sources of temporal variation described above (§2) at the level of experience on varying timescales. Upon detecting an odour, for example, we do not typically experience all of its qualities at once. Rather, there is a kind of 'blooming' or unfolding of odoriferous qualities as each individual 'note', corresponding to patterns of activation in the olfactory receptors and brain, is detected over time. While this usually takes place over a one- to two-second timeframe leading to successful recognition and identification in conjunction with other sensory modalities, the precise qualities of the odour may be elusive and so require further intake of odorants to identify. This process can continue over a considerable period of time, particularly where odour mixtures are concerned due to the inhibition and enhancement effects described above (§2.3), or environmental conditions that yield incomplete mixing of multiple odorants.

The temporal profile of flavour experience is even more complex, with a mixture of olfactory, gustatory, trigeminal, and other—e.g. somatosensory or auditory—cues occurring over an extended period. This may be further extended by the automatic or intentional actions of chewing and swallowing, enabling a degree of conscious control over the unfolding of a complex multimodal flavour profile. Good wine, for example, not only has a complex flavour profile, but one that develops and changes on the palate while—and ideally for some time after—it is being drunk. This process continues as foodstuffs interact both with each other and with the environment of the mouth and nose (§2.2), affecting the phenomenal character of the resulting experience. Flavour experience, of which olfaction forms a significant part, thus shares many of its distinctive dynamical qualities, which extend over significant intervals of time rather that consisting of mere snapshots or successions of one tastant after another.

When smelling complex mixtures, or 'smellscapes', variations in odour intensity, including concentration gradients (§2.1), capture conscious attention, alerting the subject to changes in their environment. When walking into an unfamiliar building, for example, we are immediately aware of its distinctive odour, which is a complex mixture of environmental materials. Yet just minutes later, these may be all but unnoticeable due to the olfactory system having adapted to the new baseline. Similarly, we are rarely aware of the odour of our own bodies, clothing, or perfume because they remain relatively constant. The same is not true for vision, which continues to generate experience of an unchanging scene, employing periodic eye movements or *saccades* to avoid receptor fatigue. Given the level and speed of habituation in olfaction, it seems plausible that part of the olfactory system's function is to detect and draw attention to environmental changes, rather than merely sampling the mixture of odorants that is present at any given time. This in turns suggests that at least some of the objects of olfactory experience are temporal processes, consisting in significant changes in the olfactory environment, or have a significant temporal component (§4).

Over longer timescales, olfaction can inform us about the temporal characteristics of an odour or foodstuff. Sommeliers, for example, can estimate the age or maturity of a wine from its olfactory profile. Foodstuffs may smell fresh, stale or rotten, and stale cigarette smoke has a different olfactory quality to the cigarette as it is smoked, giving an indication of how long ago the smoker was present. This kind of intermittent sampling of different time slices of an odour enables the perceiver to come to know more about the properties of its source. It is doubtful, however, that this forms part of the content of olfactory experience *per se*. Rather, the relevant time period is inferred on the basis of stored sensory profiles or prior learning. While such judgements may subsequently become so habitual so as to enter into the content of experience, they do not arise from the temporal structure of olfactory processing. Nevertheless, such judgements form an important part of how olfaction can inform us about time and temporal properties.

4. The Temporal Metaphysics of Olfaction

Olfactory experience, i.e. smelling and tasting, has a complex temporal structure. It not only occurs over extended periods of time, as do all sensory experiences, but contains various dynamical elements that reflect changes in the olfactory environment and how odorants interact with the olfactory system over time. Though the epistemic achievements of recognising and identifying odorants or their sources occur at punctuate moments, they do so on the basis of a temporally extended and constantly changing stream of olfactory experience. Indeed, the very distinction between what we consider 'taste' and 'smell' is in part determined by the relative timing of olfactory and gustatory signals (§2.5).

The essentially dynamic nature of olfaction suggests that we should move away from characterising olfactory experience *at a time* to how it changes *over time*. This is sometimes called 'diachronic' olfaction, though I prefer the term 'dynamic' as it emphasises the changing nature of the experience, rather than simply that it occupies an extended interval. On the resulting view, olfactory experience is more akin to listening to music—the complex shifting chord described in §2.3—with a series of distinct olfactory 'notes' that vary in intensity and olfactory qualities over time, and a rhythmic pulse that is connected to the cycle of the breath (§2.2) and underlying mechanisms of synchronisation that coordinate olfactory and multisensory activity in the brain (§2.4). If this view of olfactory experience is correct, what implications, if any, does it have for the metaphysics of olfaction, or our understanding of perceptual experience more generally?

If, as argued above, one of the primary functions of olfaction is to detect environment changes, this suggests that we should admit temporally extended or dynamical entities such as concentration gradients and changes in odorants themselves, as being among the objects of olfactory experience. That is, like auditory objects (e.g. sounds), some olfactory objects are extended over time such that they are not fully present at every time at which they exist (cf. §2). One way to do this would be to characterise odour objects as a kind of event. On this view, the proximal objects of olfaction are not only odorants themselves, but how they behave over time, either in the environment or in their interactions with our olfactory systems. This model can be further extended to include distal objects such that (i) the odour source, (ii) its gaseous emissions, and (iii) odorants' interaction with the olfactory system form a complex temporally extended event that is the direct object of olfactory experience. This view closely resembles the accounts of auditory perception given by O'Callaghan (2007) and Nudds (2010), and exploring these parallels further would be a fruitful line of enquiry, and compatible with both representational and Naïve Realist metaphysics.

This is not to say that all olfactory objects must be temporally structured, however. Rather, if we reject what Aasen (2019) calls the "uniformity assumption", we can allow that each sense-modality can have multiple different kinds of objects. This assumption is already widely rejected for vision, and potentially also for hearing (Phillips 2013; Wilson in press), so there seems to be little reason to insist upon it for the chemical senses. On such pluralistic views, we can think of olfaction as having a diverse range of objects, some, though not all, of which may be temporally structured. This is particularly fitting in the case of flavour experience, which involves detection of a diverse range of sensible properties across multiple modalities, and so potentially multiple kinds of objects.

Admitting interactions between odorants and the olfactory system as objects of olfaction, as described above, raises a further question as to whether this renders olfaction partly or wholly subjective. Indeed, it seems to blur the boundary between the olfactory environment and the sense-organs, since the nose and mouth effectively become part of the former. To the extent that the resulting temporal variations arise from physical changes in odorants and their interaction with the mucosa and olfactory receptors, however, there seems little reason to deny that they are objective. That is, just because these changes occur within the confines of the body does not make them subjective in the sense of being mind-dependent, as they do not depend for their existence upon the mind. Rather, just as we do not think of vision or audition as being subjective just because light and sound interact with our sensory apparatus in the eyes and ears, respectively, olfactory interactions are objective physical processes that reveal important information about the world.

A better way of characterising the relevant dependency is to consider it part of an organism-dependent *perceptual perspective*, rather than as a modification of the subject or object of perception *per se*. That is, it is characteristic of perceivers like us that we perceive odours and flavours in certain ways, where some of those ways may be temporal, multisensory, and so on. Thus we might consider cases where the process of sensory transduction itself modifies sensory stimuli as an aspect of our olfactory point of view. That is, part of what we perceive when odorants or tastants interact in those particular ways is something that unfolds over time in conjunction with our sensory systems, rather than being wholly independent of them. This enables us to accommodate the ability of the chemical senses to provide an organism-dependent perspective upon the olfactory world that is neither purely 'objective', in the sense of being wholly perspective-free, nor a mind-dependent modification of the subject; e.g. a pure sensation. Thus olfactory experience can be both perspectival and organism-dependent without rendering it subjective or indirect in any philosophically significant sense.

Finally, what does any of this tell us about perceptual experience in general? Are smelling and tasting more like hearing than seeing, or are the metaphysics of each these modalities all somewhat different? While there are obvious parallels between olfaction and audition, particularly in the way that their objects—odours or sounds—involve a series of changes over time, what is perhaps more striking is that a more sophisticated understanding of smell can help to advance our view of the other senses. As with olfaction, we do not typically, if ever, take in sensory information in 'all at once'. Rather, we engage in a process of continuing process of exploration that involves interactions between our perceptual capacities, attention, and mind-independent objects of experience. Much as the experience of an odour or flavour is built up over time by a series of olfactory interactions, our impression of a visual scene is built up via a series of saccades or glances, many of which may be automatic.

What the olfactory case highlights, however, is that interactions between sensory systems and their objects can themselves be a significant source of temporal variation. This can in turn be accommodated by an event-based account of sensory objects that draws upon the notion of a perceptual perspective or point of view. In other respects, however, the phenomenology of the non-chemical senses is arguably as infused with temporal structure as the phenomenology of smell and taste. To that extent, olfaction has as much if not more to teach us about the other senses as they do about it.

5. Conclusion

Smelling and tasting have a complex temporal structure that depends upon sources of temporal variation in the olfactory environment, sense-organs, transduction, and processing. One novel aspect of this which is perhaps unique to olfaction and gustation is that temporally extended interactions between odorants and the sense-organs themselves contribute to olfactory temporal phenomenology. Along with the temporal function of olfaction in detecting significant environmental changes, this may be accommodated by including events or processes among its objects. This need not, however, render the resulting experiences subjective or indirect in any philosophically substantive sense. Rather, it reflects the partial and perspectival nature of olfaction, which reveals not only how odorants *are*, but what they *do* when they interact with our sensory systems. In this respect olfaction is more akin to audition than vision, since both admit of temporally structured objects, though the contrast between them and the other senses is plausibly more of a difference in degree than in kind. Consequently, we should think of the chemical senses as being both thoroughly dynamical and temporal, rather than a mere as a succession of snapshots of the olfactory environment over time, though it is doubtful to what extent the other sense-modalities should be thought of in that way either.

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