Is Trilled Smell Possible? How the Structure of Olfaction Determines the Phenomenology of Smell

Penultimate version (February 2011) of a paper to appear in the Journal of Consciousness Studies. Please refer to the published version.

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Abstract: Smell 'sensations' are among the most mysterious of conscious experiences, and have been cited in defense of the thesis that the character of perceptual experience is independent of the physical events that seem to give rise to it. Here we review the scientific literature on olfaction, and we argue that olfaction has a distinctive profile in relation to the other modalities, on four counts: in the physical nature of the stimulus, in the sensorimotor interactions that characterize its use, in the structure of its intramodal distinctions and in the functional role that it plays in people's behaviour. We present two thought experiments in which we detail what would be involved in transforming sounds into smells, and also smells into colours. Through these thought-experiments, we argue that the experiential character of smell derives precisely from the structural features of olfaction, and that an embodied account of olfactory phenomenology is called for.

1. Introduction

What if it were possible to trill smells, as one can musical notes? What would it be like to experience a rapid and precise alternation back and forth between the aroma of fresh-roast coffee and the scent of a rose? Would the individual odour-samples, the 'smell sensations' that comprise the trill, be identical in quality to the temporally extended smell experiences to which we are accustomed, just briefer? Or would such extreme brevity affect their quality? When we try to imagine such an olfactory trill, is it really possible to imagine complete samples of *smell*-experience within it, or is there some tension here which forces us to alter the character of the experience so that it is no longer truly olfactory? Is trilled smell conceivable?

One's answers to these questions depend on how one thinks of experience. A traditional conception, captured in the notion of 'sensation', would say that there is nothing inconceivable in this idea of trilled smell. A sensation is, by definition, an atom of qualitative experience that can be characterized independently of its context and of its subject. There is a "something it is like" to experience it. According to a sensation-view of smell-experience, no matter how small a temporal portion of olfactory-experience we sample, we will still be sampling an atom of smell, a pure olfactory sensation with all its quality intact. There would be no reason to believe, then, that the essential quality of the smells involved in trilled olfaction should differ from that of the more temporally extended olfaction with which we are familiar.

The conclusions to which such a sensation-based conception of experience lead closely resemble those arising from what we will call here the *independence thesis* in the philosophy of perception. According to this independence thesis, the character of perceptual experience enjoys a degree of freedom with respect to the spatio-temporal processes involved in perception, neural and other. There is a gap, minimally epistemic, possibly ontological, between the character of perceptual experience and processes of the latter kind. The same physical (spatio-temporal) events could, really, or at least conceivably, give rise to different experiences; and the same experiences could be due to different physical events.

A priori claims of such independence, often based in thought-experiments, have enjoyed much success in the philosophy of perception (Block, 1995; Nagel, 1974). They typically invite us to consider an experiential quality –normally the colour red- and to agree that it has no internal spatio-temporal structure, despite its obvious phenomenal character. If that much is conceded then the task of relating such experience to physical, spatio-temporal events seems intractable. On the physical side of the proposed relation, we would have spatio-temporal dynamics and structure; but these would then have to be matched up, on the other side of the equation, with static and structureless experiential quality.

Various proposals have nonetheless been made contra the independence thesis.
It has been challenged with respect to four proposed sources of structure – distinguishable, though perhaps overlapping- in perception and its dynamics that, it has been argued, can also be found in experience itself. First, it has been pointed out that the nature of the stimuli which cause an experience strongly constrain the quality

of the experience (Hurley, 1998; Myin, 2001). Recently, the specific sensorimotor ways of environmental exploration that underlie experience, it has been claimed, also fix its sensory quality (O'Regan & Noë, 2001; Hurley & Noë, 2003); thirdly, the idea has been defended that the phenomenal qualities of perceptual experiences can be defined in terms of their intramodal relations of similarity and difference (Clark, 1993). Finally, functionalists think that the functional profile of an experience leaves no room for variation in its phenomenal quality (Cole, 1990). Of course, some authors have invoked a combination of these factors in making their case against independence. (See Dennett, 1988,1991 and Pettit 2003, 2004)[1]

But while these factors have been admitted to play some causal role, defenders of the independence thesis have often had recourse to thought experiments, for instance colour-inversion thought-experiments, to show that each of these factors can vary without variation in phenomenal character, or that each of these factors can remain constant, with variation in phenomenal character (Block, 1990).

In the case of the specific stimuli and the specific ways of exploring the environment, it is then argued that such factors may cause specific experiences (even if the causality is obscure and poorly understood, as in the case of colour), but neither the

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[1] These structural factors, though distinguishable on the conceptual level, do not necessarily form mutually exclusive categories. Moreover, the specification of the nature and the boundaries of those structural aspects are not independent of fundamental theoretical commitments. For example, it could be claimed that sensorimotor dynamics is an aspect of functional role (Cole 1990). Similarly, it could be argued that intramodal relations of similarity and difference are determined by activities of distinguishing and sorting (Pettit 2003, 2004). Though we are fully aware that our distinctions are less than perfect from a purely analytic point of view, we nevertheless cling to them because of the pivotal role these distinctions have played in the dialectic of contemporary discussions of the phenomenal character of perceptual experience.

stimuli, nor the ways of exploring, fix the sensory quality (Chalmers, 1996; Prinz, 2008).

As for intramodal relations, it is acknowledged by many that for example colours can be arranged in a quality space (Clark, 1993), which reveals relations of similarity and difference of colours (orange lying between red and yellow, red being opposed to green etc); but at the same time it is frequently doubted that the structural signature provided by such a space also determines the qualitative identity of the experiences (Palmer, 1999). Similarly, no one will deny that specific experiences have specific profiles in the mental functioning of experiencers, but again it is commonly thought that such psychological profiles are insufficient to fully mould phenomenal identity (Block, 1995).

Much of the recent discussion on this issue has been centered on vision. The modality of smell, altogether unable to attract much philosophical attention, has a rather marginal presence (but see Batty 2010a, 2010b). But when it does surface, it tends to be presented as an example that obviously fits the independence thesis. That smell should have assumed this role is undoubtedly tied to the fact that smell-experience does not exhibit much in the way of structure. A typical characterization of smell can be found in David Chalmers' seminal work, The Conscious Mind (1996):

> Smell is in some ways the most mysterious of all the senses, due to the rich, intangible, indescribable nature of smell sensations… smell has little in the way of apparent structure and almost seems to float free in the sensory manifold.

(Chalmers, 1996, p.8)

Chalmers' description is typical in finding no positive means to describe smell-experience, because of its lack of readily apparent internal structure; and in arguing from the point that such apparent structureless-ness coexists with great experiential richness, that olfactory experience is in crucial respects independent of any imaginable physical process.

Other critics have thought to question approaches that would tie patterns of interaction to the nature of smell experience. Here is Nicholas Humphrey attacking O'Regan and Noe's sensorimotor theory of consciousness on such grounds:

> When we … smell musk in our noses ... how can these experiences plausibly be thought to depend on sensorimotor contingencies? There is simply nothing we do by way of exploration with … our noses. . . that could provide requisite information.
>
> (Humphrey, 2001, p.987)

Similarly, Jesse Prinz has argued that the correlation which one would expect to obtain between smell-experience and movement is quite simply absent in the case of smell.

> The enactive view becomes even less plausible when we move beyond vision. Consider two perfumes: they may smell different even if they do not have

different consequences for action (especially if they are equally appealing). Do we sniff different smells differently?

(Prinz*,* 2006*,* p.11)

Meanwhile, arguments for the ways in which intra-modal relations might fix the experiential quality of smell are susceptible to the same objections made of colour, but yet more so, for the reason that nothing approaching a satisfactory 'space of smell' has been proposed in the way that it has for colour, denying thinkers the resources even to make the case that smell experience might possibly be read off from it.

In all these ways, to the extent that debate in this area has tackled the phenomenon of smell, it has been doubted that the character of experience of it could be dependent upon the spatio-temporal dynamics of smelling.

But is the independence thesis true, or even plausible for smell? To investigate that, we will proceed in two steps. First, we will review some of the scientific literature on olfaction, with a view to establishing whether and how the perceptual and dynamical structure of the physical act of human olfaction is articulated on the four proposed dimensions of possible dependence: the physical, sensorimotor, intramodal and functional. We will argue, contrary to the prevailing assumption, that olfaction has a distinctive profile on all four counts. Second, armed with this richer description of the structure of the physical processes that seem to be involved in enabling smell experience, we will offer some thought experiments, whose aim will be to highlight how these structures may relate to the experienced quality of smell.

Specifically, we will explore in detail, in consonance with a *dependence view*, how a non-olfactory form of experience (a sound 'sensation') might acquire olfactory phenomenology because of the gradual replacement of the structural features of the modality in which it appears with those present in olfaction. We will then investigate how a smell 'sensation' might gradually have its phenomenal character transformed to colour-likeness by transforming the structure of the olfactory modality to resemble those of colour vision.

2. The structure of olfactory perception

2.1. Physical

Smells reach us far less efficiently and directly than sounds and sights. The primary reason for this is that the nose, unlike the eye or ear, is stimulated by physical molecules as opposed to waves of energy. Before olfaction can begin, volatile chemicals thrown off from objects must reach us on the air, and enter the nose.

The passage of smellable chemicals through air is a chaotic, unpredictable business accomplished by a mixture of air movement (due to some combination of wind, heat-convection, sniffing and deliberate wafting) and diffusion (Murlis, 1986). Because of the contingency of these forms of transport, the arrival of an odour at the nose follows very indirectly from its emission at source, and, as a result, it is normal for odours from many sources to be contained in any given sample of air.

Adding to the ecological challenges facing the olfactory system, the number of distinct molecular components present in most natural scents is large, frequently running into the hundreds. The aroma of pressure-cooked pork-liver, to take one example, contains 179 compounds (Mussinan & Walradt, 1974). Meanwhile, these components that together make up a scent may differ in concentration by several orders of magnitude (Dobson, 1994). If we factor in that combinations of molecules in smell-plumes are exceptional fleeting (Crimaldi, Wiley & Koseff, 2002), we can see that an ecologically representative sample of air may contain a fast-changing concoction of thousands of distinct smellable molecules at very different concentrations that stem from numerous sources.

There are no decisive answers at present regarding the question of the physical features of the molecules to which our noses are sensitive. What is clear is that air-borne chemicals are detected by the olfactory system when, having entered the nares, they pass over the olfactory epithelium, an innervated area inside the nose spanning, in humans, around 10 cm2. There, these chemicals bind with specific receptors on the olfactory cilia.

Minute differences in the chemical composition of molecules can be detected here: with humans capable of distinguishing molecules that differ by just a single carbon atom (Laska and Teubner, 1999a), and those that are identical, except mirror-reversed (Laska and Teubner, 1999b).

Generally speaking, the kinds of molecule to which we are sensitive seem particularly to be associated with the identity of, and transitions of state within, the biological: putrefaction, seasonal change, ovulation or ripeness (Howes, 1987).

2.2. Motoric

Smell enjoys a complex motricity, with the act of sniffing now considered in some quarters "as integral to olfactory perception as the eye-movement is to visual perception" (Mainland & Sobel, 2006).

Some degree of airflow through the nostrils is a necessary condition for any olfactory perception at all. Proetz (1941) was among the first to fasten onto this fact, and demonstrated it in lectures by pouring an aromatic solution of Eau de Cologne into the nose of a supine student volunteer, who would smell nothing despite his nose being full of the perfume. Later, Bocca and colleagues (1965) more robustly established that the actual passage of air over the olfactory epithelium is essential to any olfactory perception. He and his colleagues intravenously injected odorants so that participants' olfactory receptors were constantly stimulated from the inside, and thus independently of air-flow; it was found that participants were only able to smell the injected odorant when air was actively passing through the nose.

Not only is airflow necessary for olfactory perception, it is also sometimes sufficient. Wenzel (1949, 1955) found that a mere blast of air into the nostrils often produces an olfactory percept. Underlying this, both the act of sniffing odorless air and having it blown into the nose produces activity in the olfactory bulb (Hughes, Hendrix, Wetzel & Johnston, 1969) and olfactory cortex (Sobel, Prabhakaran, Hartley, Desmond, Zhao, Glover, Gabrieli & Sullivan, 1998), even if such responses are less pronounced than those that occur with odorous air.

Since during resting respiration only 5-10% of inhaled air reaches the olfactory epithelium, the sniff, which serves to pull typically around ½ a litre of air over our olfactory receptors in the course of, on average 1.6s, (Laing, 1983) is ubiquitous to all sustained smelling (Hahn, Scherer and Mozell, 1994)

The relation between smell-percepts and sniffing-behaviour is exceedingly complex. The first factor behind this is that the majority of odorants in a sample of air are absorbed during inhalation, so that when air is exhaled, it carries a different, and reduced, concoction of odorants. Though we can and do perceive these odorants during exhalation, such retro-nasal olfaction, which is important to our sense of taste, produces different smell-percepts (Rozin, 1982), accompanied by distinct odour-evoked potentials (Heilmann and Hummel, 2004) to those evoked by the same combination of odorants traveling in the opposite direction..

In addition to the influence of the direction of air-flow, air-speed as a result of sniffing also affects the olfactory percept. Le Magnen (1945) found that the detection-thresholds for odorants at particular concentrations depended not on the total amount of air inhaled, but on the speed at which it was inhaled. He showed that odorants at lower concentrations required a stronger sniff in order to reach threshold, whereas more intensely concentrated odours could be detected with lower sniff-speeds. The interaction between sniff-velocity and the intensity of the resultant olfactory percept is of course evident to experience: a deep, slow breath generally presents us with a light, prolonged experience of odour, whereas sudden inhalation gives us a shorter, more intense experience.

Although vigorous inhalation increases the intensity of olfactory response and experience, we adjust our expectations of stimulation from sniffing according to the vigour of our sniff. A form of perceptual constancy in our estimates of odorant-intensity obtains, where, by factoring in how hard we are sniffing, we can reliably perceive the objective intensity of an odour (Teghtsoonian and Teghtsoonian, 1982; 1984). That this is a sensorimotor adjustment was shown by Yuongentob et al. (1986), who found that under conditions where sniff-effort is held constant but where a change to the resistance to inhalation reduces air-flow, people mis-perceive the intensity of odors as a function of their sniffing-effort: 'believing' themselves to have sniffed more, they under-estimated stimulus-intensity.

To control the degree of olfactory stimulation, we adjust the vigour of our sniffing-behaviour in real time in response to the intensity of smells. When we encounter a concentrated odorant, we reduce sniff-velocity, just as we increase it for weaker odorants. This has been shown with a range of olfactory stimuli at widely varying concentrations (Walker, Kendal-Reed, Hall, Morgan, Polyakov & Lutz, 2001; Warren, Walker, Drake & Lutz, 1994). Johnson et al. (2003) meanwhile found that such adjustments to odorant intensity may occur as soon as 160 ms into a sniff: which is minimally more than the time required for the mere transduction of the stimulus, estimated to be on the order of 150 ms (Firestein, Shepherd & Werblin, 1990). Alongside these adjustments to sniff-vigour, people also spontaneously adjust sniff-duration in response to odorant concentration (Sobel, Khan, Hartley, Sullivan &

Gabrieli, 2000).

Not only the concentration of the odor, but also its pleasantness affects sniffing behaviour, with unpleasant aromas tending to be sniffed less vigorously, and for shorter time periods, than pleasant aromas, an effect that is manifested in, and predicts competence in, olfactory imagery (Bensafi, Porter, Poulio, Mainland, Johnson, et al. 2003; Bensafi, Pouliot and Sobel, 2005).

A single sniff, it has been shown, is generally sufficient to detect and sense the intensity of an odour, but odour-identification often involves a prolonged spell of repetitive sniffing- especially in smell-samples containing complex multitudes of smellable molecules. Mainland, Khan & Sobel (2004) have, for instance, shown that a second sniff is beneficial in identifying odorants in binary combination.

The optimal rate of sniffing for the differentiation of odours seems, in rats, to be between 6-9 hz (Kepecs, Uchida & Mainen, 2006), and this is on the same temporal order as the spontaneous sniffing behaviours when humans are paying close attention to an odour. It has been suggested that such rate of sniffing represents the sweet-spot for our olfactory sensitivity: the most efficient way to ensure the most stimulation in light of physical, sensory and neural temporal constraints. Another reason, relevant to trying to pick out single aromas from complex multitudes, is that passing air energetically over the olfactory epithelium helps adapt out dominant aromas, leaving the field open for attention to less salient ones hitherto hidden ‘beneath’.

There are undoubtedly neurophysiological factors too: notably, sniffs seems to drive, and be related to, the slow theta oscillation (3-12hz) known since the work of Freeman (1960) to occur in olfactory bulb and cortex, alongside a quicker gamma-oscillation (30-100Hz). High-resolution recording from the olfactory bulb of rats has revealed highly detailed odorant-specific spatiotemporal activity, altering both within and across sniffs (Spors and Grinvald, 2002), that would seem to indicate that sniffing may play a role in coordinating a phased series of olfactory snapshots, as a stimulus is progressively categorized (Freeman and Barrie, 1994).

To encounter smell-receptors, the volatile chemicals to which our noses are sensitive must sorb to and then diffuse through a very thin layer of mucus that is sustained over the olfactory epithelium. Because smaller particles sorb to this mucus more easily than large ones, the early stages of a given inhalation tend to yield detection of 'lighter' notes in an odour, with 'heavier' 'bass' notes detected later in the arc of inhalation. By smoothly, slowly and attentively inhaling, we can, therefore, effectively parse a complex aroma: a maneuver familiar to wine-tasters.

Mozell and colleagues have shown that speed of inhalation interacts with the different rates at which odorants sorb to and diffuse through the nasal mucosa (Mozell and Jagodowicz, 1973). They later found that an odorant that is easily absorbed into the mucosa will produce a large response when delivered at a high velocity and a lower response when airflow is slower; contrast this with the responses occasioned by an odorant that sorbs slowly into the mucosa, which will induce its greatest response at a low airflow, and a lesser one at a higher airflow (Mozell, Kent and Murphy, 1991).

The reasons for this interaction are that the best olfactory responses occur when there is an even pattern of absorption along the whole epithelium: enabling the greatest number of receptors to respond to the stimulus. If a high-sorption odorant is breathed in too slowly, it will all be sorbed along the anterior portions of the epithelium, with the posterior portions going un-stimulated and the net response correspondingly reduced. Where there is a low-sorption odorant, by contrast, a low speed of inhalation will produce the most even pattern of absorption, with higher speeds resulting in only the posterior portions of the epithelium getting 'fed', and much of the odorant passing into the lungs without having been detected at all.

This interaction seems to be the reason behind the well-attested fact of odorant-specific patterns of absorption along the olfactory epithelium (Moulton, 1976; Kent, Mozell, Youngentob & Yurco, 2003). It is also responsible for the fact that the perceived identity of an odorant can be modulated by sniff-velocity. This was demonstrated by Sobel et al.(1999), who showed that the same mixture of odours can be perceived differently depending on the speed at which it is inhaled.

One way of thinking about this aspect of olfactory function is as a form of dynamic chromatography, with complex aromas separated out by virtue of their components' different styles of interaction with mucosa, a process that is perhaps tuned by targeting particular sniffs at particular aromas, or categories of aroma.

Mainland and Sobel (2006) indeed suggest that the olfactory system "pretailors" sniffs, optimizing them for, for instance, "that particular note of spoiled milk"; they point out that that, ideally, the olfactory system "would optimize sniff velocity, duration and number of sniffs in a bout for each odorant it set out to detect, and each task it set out to perform" (p. 190).

Our ability to move our noses and to sample air in extended fashion over time provides the basis of smell's substantial spatiality. To judge the spatial provenance of a smell, we put into practice of a certain amount of accumulated know-how about the ecological distributions of smells; specifically, we exploit the intensity gradients within smell distributions. (Von Scramlik, 1924; Kobal, Van Toller & Hummel, 1989)

Because odorant-concentration tends to decrease with distance from odorant-source, an increase in the perceived concentration of an odorant as we move indicates that we are approaching the source of the smell.

Recent research reveals that we make use of our two nostrils, just as we do our two ears and our two eyes, as a means of enhancing the quality of our olfactory spatial discriminations. By exploiting binaral disparity- a capacity first evidenced by Von Bekesy in 1964- humans can even track (strong) scent trails: Porter et al. (2007) found that participants could weave along winding paths of chocolate on the basis of its scent. That their performance was impoverished when using only one nostril, showed the active use of the disparity information; further tests indicated that the two nostrils seemed to be sampling portions of air separated by 3.5 cm, and that quality of performance-improvement with practice was accompanied by an increase in the frequency of sniffs, as one would expect from the greater temporal resolution of smell-samples that results. Interestingly, just like pigs and ants, participants in these studies spontaneously exhibited the tendency to oscillate either side of the scent-trail as they proceeded.

Our olfaction can typically locate just one smell at a time. Frequently, though, we more or less simultaneously track two or three smells, often using some degree of help from the other modalities- as when, with three bottles of milk arrayed before us, we seek out the one which has gone off by putting our nose to each in turn. In tracking multiple smells spatially, we may even put into practice subtle acquired know-how of the behaviour of gas- as when two differently perfumed people pass us on the street and we map the relevant aroma to each some seconds after they have passed.

2.3. Intramodal relations

To conceive of the network of distinctions of which olfaction is capable, it will be useful to consider a little more of the neurophysiology that underlies smelling.

The olfactory epithelium has around two million olfactory receptors, of which it is estimated that there are around four hundred distinct varieties, each tuned to the recognition of specific features of odorant molecules (Buck and Axel, 1991). Though it is not known to what extent the transduction that occurs is a result of molecular or sub-molecular features of the stimulus, a given smellable molecule has been shown to activate a range of these receptors (Sicard and Holley, 1984), though no two receptor types are thought to have the same global response properties across stimuli.

Though widely and irregularly dispersed on the olfactory epithelium, each receptortype projects, in a paragon of neurophysiological convergence, to a proprietary location in the glomeruli of the olfactory bulb (Belluscio, Lodovichi, Feinstein, Mombaerts & Katz, 2002), which thereby furnishes a spatially organized mapping of odorant features (Sullivan & Wilson, 1995). Lateral inhibition and convergence within the olfactory bulb seem to enhance this "feature map" (Yokoi, Mori & Nakanishi,1995); and the mitral cells that output to the olfactory cortex from the olfactory bulb thus have relatively precise feature-detecting receptive fields (Mori, Takahashi, Igarashu & Yamaguchi, 2006). It appears that precise temporal patterning of spike trains over populations of these output neurons further contributes to the specificity of neural activity associated with particular odorants (Laurent, Stopfer, Friedrich, Rabinovich, Volman &Abarbanel, 2001)

One way of conceiving of this, is that these four hundred or so distinct receptor types provide a gigantic alphabet of features, fed to subsequent brain areas for further processing. From such a view, one might expect that olfactory abilities and phenomenology should derive in some way from combinations of these features, as the sounds of words do from their letters.

Research in neurophysiology and psychology however suggest that we have precious little behavioral or subjective access to the kind of individuated olfactory features that can justify such an analytic treatment of smell-space. For we appear to analyze odours synthetically, as wholes, and not in terms of their constituent parts (Wilson and Stevenson, 2003). Given that natural odours are often comprised of a vast number of distinct odorants, and that a given sample of air is normally influenced by several such sources of aroma, there is good reason for olfaction being this synthetic: in the absence of spatial differentiating factors, it is unclear how the very complex odorant mixtures that enter the nose could ever be separated out into distinct odours, or how individual odours could ever be distinguished from background ones (Gottfried, 2009). The evidence for the synthetic character of odour-perception is wide-ranging.

First, humans, even experts, turn out to be almost completely incapable, across a wide range of measures, of identifying an odour as present in a multi-component mixture featuring four or more distinct odours (Livermore and Laing, 1996).

Our lack of access to the components of complex smells is also reflected in both behavioural and subjective judgements of complexity, in which, beyond at most three components, people cease to find odours subsequently more complex (Laing and Francis, 1989). Smells are perceived as wholes, and not in terms of their constituent parts. This assumes a strong role for learning and memory in olfactory perception, a role borne out by the empirical research. People are poor at discriminating novel odours, but improve rapidly with exposure (Jehl, Royet & Holley, 1995). Experts, meanwhile, have been widely shown to be better than non-experts at discriminating smells in the domains in which they have trained, even taking into account the linguistic skills that form a part of their expertise. (Hughson and Boakes, 2001)

Moreover, perception of odorant identity is heavily dependent on past experience: if you expose people to binary pairs of odour, those odours tend subsequently to acquire in perceptual experience each others' characteristics, when presented in isolation (Stevenson, 2001a). For instance, the pairing of a novel cherry-odor with a novel smoky-one, leads to the cherry one subsequently being perceived as more smoky and the smoky one being perceived as being more cherry-like. Such a role for memory in constituting odour-percepts is also reflected at the level of basic perceptual discrimination (Stevenson, 2001b).

The neural basis for these effects appears to be in the anterior portions of the piriform cortex, to which the mitral cells of the olfactory bulb feed. A recent series of experiments have shown in rats that habituation to pairs of odorants does not lead to habituation of the constituent odours. That is, complex odours and their components enjoy different, and unique, correlates in the olfactory cortex- striking evidence at the neural level of the non-hierarchical, synthetic, nature of olfactory perception (Wilson, 2000).

Scientists are just touching the tip of the ice-berg when it comes to the ways in which context and attention influence the geometry of olfactory perceptual space. A few recent empirical examples hint at the richness of the area.

Li et al (2006) found that three and a half minutes of exposure to a particular variety of smell (a floral aroma) led immediately to an enhanced capacity to differentiate between 'nearby', related, floral odors. FMRI evidence seemed to indicate that the degree of transformation in the discriminatory ability was tied to the degree of learning-related changes in piriform cortex, so that this capacity was at least partially due to plasticity in neural structure.

Smell-differentiations moreover seems to be significantly influenced by perception of object identity, so that odours are perceived differently according to the verbal labels attached to them: participants in a study by Herz and von Clef (2007) perceived the odour of cucumber differently when told that they were smelling mildew.

Emotional factors have also been shown to influence the olfactory distinctions of which a person is capable, and thus the shape of their olfactory perceptual space. Li, Howard, Parrish and Gottfried (2008) found that participants could be led to discriminate initially indistinguishable smells by a process of aversive conditioning (footshock paired to just one of the two initially indistinguishable stimuli). By scanning the brain, they found that aversive learning encouraged piriform plasticity, as the system, so to speak, searched for differentiating cues to help tell apart the harmful from the benign.

All in all, extraordinary cortical plasticity, influenced by diverse experiential, linguistic, emotional, and intermodal factors determine the gamut of differentiations of which our olfaction is capable. The space of difference between smells is thus extremely obscurely related to the molecular features that determine olfactory transduction, and the 'feature' maps that result.

How, then, are we to think about the relation between these smells? Because of the role for experience, language and emotion in developing the capacity to differentiate smells, the relationships of similarity and difference between smells is far more contextually variable, complex and individual than for any other modality.

Returning to the metaphor of an alphabet, we might say that the four-hundred or so letters (feature-detectors) seems to generate a vocabulary of a much greater number of discriminable smells: typically around 10,000 in humans (out of the more than 400,000 that the nose is estimated to be capable of learning to distinguish (Mori, Takahashi, Igarashi & Yamaguchi, 2006). But just as one's mother tongue is determined by one's early linguistic environment, and the words one ends up knowing are further influenced by the conditions of one's development, so too is the space of olfactory discrimination enormously influenced by the historical details of one's exposure to smells. The extraordinary thing on top of this, if we retain the notion of olfactory features as letters in an alphabet, is that we can distinguish the words these letters give rise to, without being able to experience or report all the letters of which they are composed. There is something quite unfamiliar in the notion of differentiation between objects without the kind of robust attentional access to object features that characterizes a modality such as vision.

Although there has been little success in converting on Hans Henning's (1916) dream of discovering “primary odours” (he argued that there were six), sophisticated techniques have been put to work to estimate the dimensionality of smell-space. Mamlouk and Martinetz (2004), applied multi-dimensional scaling techniques to the patterns of dissimilarity revealed by analysis of a large dataset that included 851 smells each described by 171 non-unique descriptors. They estimated smell-space to have a minimum size of between 32 and 68 dimensions.

If we bear in mind that similar assumptions reveal colour space to have just three dimensions, this gives some insight into the challenges facing someone who wishes to describe smell space.

2.4. Behavioural

Smells are known to produce more affective reactions than either auditory or visual cues (Hinton and Henley, 1993). And with olfaction's low spatiotemporal resolution, and strong bias towards the detection of compounds of biological origin, it is natural that it should specialize in the qualitative perception of foods, people and threats (Stevenson, 2010).

Perceived taste is of course largely dominated by our sense of smell (Auvray and Spence, 2009), and olfaction plays a role at every stage of an 'ingestive episode', from evaluating foods prior to bringing them into the mouth (Fallon and Roxin, 1983), to mediating expectancy violations as food enters the mouth (Yeomans, Chambers, Blumenthal & Blake, 2008), to learning about the delayed bodily effects of foods (Capaldi and Privitera, 2007). Learning inevitably plays a vital role in associating smells to their tastes and delayed nutritional consequences, and it is notable that when we associate an odour with a pleasant taste, that odour is subsequently judged to be more pleasant (Zellner, Rozin, Aron & Kulish, 1983), while odour associated with unpleasant tastes tends subsequently to be judged to be less attractive (Beayens et al, 1990).

Smell undoubtedly plays a role in mediating patterns of affection between people. Neonates exhibit reduced stress and arousal on smelling their mother's odour (Schaal, 1986). A similar effect shows up in adults: Shoup, Streeter and McBurnley (2008) found that both men and women report sleeping with the clothes of an absent lover or family member. <u>Smell plays</u> a clear role in affecting judgments of sexual attractiveness, meanwhile, and this effect seems to be especially dominant among females (Franzoi and Herzog, 1987). Strikingly, and in a disappointing result for plastic surgery, physical symmetry also seems to correlate with bodily odour, with fertile females showing a preference for the odours of symmetrical over asymmetrical men (Thornill & Gangstead, 1999). There is also evidence that genetic suitability for mating can be perceived through odour (Wedekind and Furi, 1997).

Smell assists in the detection of both microbial and non-microbial effects on the human body, distinction that is reflected in the different emotions the two classes give rise to: non-microbial threats (e.g. tigers) consistently stimulate fear, with microbial ones (e.g. old socks) eliciting disgust (Stevenson, 2010). Learning plays a key role here, with humans quickly learning to dislike odours associated with negative physiological effects (Van den Bergh, Stegen, Van Diest, Raes, Stulens et al. 1999).

It is commonly remarked that smell has a special connection to memory; this despite the lack of specificity to olfactory memories, which tend to pick out epochs over events (Casey, 1987). The distinctively mnemonic character of olfaction seems to derive instead from its ability to reinstate emotions (Willander and Larsson, 2007), a capacity that is no doubt mediated by its exceptional endurance (Miles and Jenkins, 2000), together with the olfactory cortex's close connections to the limbic system (Nieuwenhuys, Voogd & van Huijzen, 1988). Autobiographical memories cued by odour, as opposed to verbally, tend to date from further back in a person's life (Chu and Downes, 2001) and are notable not just for their age, but for their intensity, clarity and emotional tone (Herz and Cupchik, 1992).

In these ways, the functional role that smell has come to play in human life is focused on the qualitative evaluation of biological entities, whether foods, threats or people. It is for these functions, no doubt, that smell's mnemonic endurance and emotiveness evolved, characteristics which have lent it a wider role in our psychological life in connection to emotional dimensions of autobiographical memory.

2.5. Smell experience and its relation to the spatiotemporal

The foregoing empirical research seems to allay some of the doubts raised by Prinz and Humphrey over whether there is anything by way of movement that might help explain olfactory experience. Contra Prinz, we do smell different smells differently- even when they are equally pleasant. Contra Humphrey, far from there being "nothing that we do by way of exploration" with our noses, there is an astonishingly rich interplay between the nature and location of olfactory stimuli and our movements- the displacement of the nose itself; the speed, duration, frequency and number of our sniffs; and the forms of action enabled, or not, by smelling.

We should now be able to see that Chalmers' description of smell, which is in its way accurate to the experience, is also accurate to the spatiotemporal structures of smelling. Chalmers, recall, noted smell-experience's intangibility, indescribability and richness, and he was impressed with how it seems to "float free in the sensory manifold".

Evidently, his description corresponds nicely both to the physical stuff of smell, and to the kinds of action that it affords. The stuff of smell is indeed intangible- volatile molecules cannot be palpated; we are sensitive to four hundred or so distinct classes of molecule, synthetically combined, into around 10,000 discriminable odours dimly connected in a space of vast dimensionality: this is naturally going to be somewhat ineffable; and smells are emotive, being focused on the qualitative evaluation of biological entities- which naturally predicts experiential richness. That smell gives the appearance of floating free in the sensory manifold is exactly mirrored by what it does both physically in the air, and in relation to our actions, to whose fine coordination it cannot and does not contribute.

In this way, there is nothing especially elusive about the character of olfactory experience in light of the spatiotemporal events that sustain it, and we should be skeptical of straight-out, shoot-from-the-hip, assertions of the impossibility of relating smell-experience to what happens as we smell.

It is important to appreciate how apparently negative properties -intangibility, vagueness and so on- are only negative in relation to the particular standards of other modalities. It is true that smell is less spatiotemporally acute than vision, for instance, but we should not forget that smell has a distinctive and positive spatiotemporal profile of its own. Moreover, as we have seen, vagueness of one kind is not vagueness of all kinds: we should not over-value the perceptual capacity to locate objects in space-time, as against that of determining, for instance, their position in biological space.

The foregoing discussion of olfactory research shows, we think, that the character of olfactory phenomenal experience might very well be dependent on olfactory structure. But we have said nothing so far of how experience is supposed to map to spatiotemporal aspects of what is happening physically. Knowing that the dependence thesis is not implausible does not make it right: it does not help us see how the two levels of olfactory experience and physical structure and dynamics relate, and neither does it help us to see that they relate exhaustively, that nothing is left out.

Insofar as this is not clear from the foregoing, we intend the dependence thesis to hold that the phenomenal nature of both a modality and its contents are *entirely* dependent on the sorts of structural feature that we have identified in our discussion of olfaction thus far. That is to say that there is nothing in the smell of a rose *except* what derives from the structure; that there is nothing in the difference between the light of a candle and the smell of that rose except, again, what can be isolated among the structural elements of the perception underlying those two perceptual situations.

To put this in positive terms, if the dependence thesis is correct, it should be possible to transform a sensation in one modality [e.g. a colour] into a sensation in another modality, simply by replacing the structural features of the source modality with those of the target modality. This is a straightforward consequence of the view that the character of the experience can be read off from such structural features.

Jesse Prinz, alert to this prediction, heaps ridicule on the very possibility that such a transformation could occur in the case of olfaction. Here, he sketches a brief thought-experiment to help us consider whether a sound, with the right structure, could become a smell:

> “we all know that the sound of a smoke alarm signifies the presence of smoke, but that does not mean that we smell smoke simply by hearing the alarm go off. Could a congenitally anosmic subject, deprived of olfaction, suddenly experience the smell of smoke after being trained to interpret the significance of a smoke alarm?” (Prinz 2006, pp. 4-5)

Prinz thinks not. And on the face of it, the thought that the anosmic would experience the smell of smoke simply because she knew the significance of the sound of the smoke alarm is indeed rather implausible.

In Prinz's example, though, no attention is paid to the distinction between the symbolic and sensory significance of fire-alarms- which are designed to communicate information neither about the sound or smell of smoke, but instead the brute fact of its presence. This distinction is crucial, for as we have seen in our review of the scientific literature on olfaction, the sensory significance that the anosmic would need to acquire is certainly not of the order of a few facts that might “suddenly” be acquired. None of the structural, dynamical, intramodal or functional aspects of the modality are present in Prinz’s imaginings. In this way, we should reject the proposed test-case in its current form, since it fails genuinely to interrogate the issue.

Despite the flaws in its formulation, the question of how sounds could ever assume the experiential character of smells merely as a consequence of the spatiotemporal characteristics of the underlying perception, nevertheless gets at the heart of the question of smell-experience and its relation to the physical world: for the dependence thesis indeed predicts that hearing would be subjectively indistinguishable from smell if it adopted smell's structures. And this remains deeply resistant to intuitive affirmation: a tremendous leap of imagination is required to see how an experience of sound could assume the phenomenal character of an experience of smell, if only the context of its occurrence was olfactory.

In the next section, we will seek to engage with these questions. We will describe in detail two imaginary transformations of one modality into another. First, correcting and fleshing out Prinz's thought-experiment, we will take audition as our source modality, and olfaction as the modality whose characteristic structure we will try to imagine that audition assuming. The crucial question is this: as we gradually transform audition's structure and dynamics, are we compelled to imagine a corresponding change to the phenomenal character of the modality? If the dependence thesis is right, then sound sensations will gradually be dissolved and replaced by smell sensations. If, on the other hand, we are able to imagine audition assuming olfaction's structure while retaining the native character of its sound sensations, then the independence thesis will be supported: such phenomenality will appear independent of the processes underlying it.

In the second thought experiment, we will set out from olfaction, and move towards colour: we will explore what would be involved in giving olfaction the structural characteristics of colour-vision, and ask now the question whether imagining this in detail will result in us assenting to the dependence thesis' claim that the resultant phenomenal feel of such smells would be indistinguishable from that which normally accompanies colour-perception[2].

3. Morphing modalities

3. 1. Olfactorized audition

In our first thought-experiment, then, we will attempt to modify the structures and spatio-temporal dynamics of hearing so that they begin substantially to resemble those of olfaction.

3.1.1. Physical factors

Smells, we saw, are gradually emitted by a certain class of normally biological objects and waft and bounce through the air towards us, in relatively leisurely, somewhat unpredictable fashion.

Our first move should be to modulate the physical distributions of our imagined

[2] These thought experiments are obviously related to the actual phenomenon of sensory substitution, in which subjects receive stimulation that is normally in one modality -vision, for example - through another modality - touch or audition, for example. Though undeniably more empirical than the thought experiments we'll engage in, sensory substitution also brings problems of interpretation (Auvray & Myin 2009), which we attempt to avoid by not further mentioning the topic here.

sounds so that they imitate the actual physical distribution of smells. Imagine individual sound-waves emitted by, for instance, a banana, as standing oscillations, moving in plumes, lacking any native velocity, dispersing slowly in the air. It may help for the imagination to picture these sounds as a kind of vapour; and we should take care to imagine that the events which give rise to this sound vapour should be appropriately distinguished from those that give rise to normal sounds.

The air should generally be full of a great melée of volatile sounds thrown off from the kinds of object that typically emit smells. Sound-vapour should thus emerge from foods, humans, dustbins, ovens and so on, but not, for instance, a tin of coins, however hard one were to shake it. It is important to note that events we instinctively identify with their loudness would frequently lack that characteristic: if sounds moved like smells, then in a gun-fight we'd not hear the shots, except perhaps at the moment when the acrid sonic fumes reach us, having wafted over the battlefield. Noises would thus lose their capacity to alert us to sudden nearby events.

3.1.2 Sensorimotor factors

The ear-drum must be imagined in the nose. A microphone placed inside the nose feeding sounds in real time to noise-defeating headphones would exactly mimic the sensory consequences of the ear-drum being surgically implanted in the nose.

If one were to do this, the nearer one moved one's nose to a source of sound the louder it would become, with the most intense auditory-perception resulting from placing one's nose right up against a sound-source. If the ear-drum was in the nose, that is, exploration would quickly reveal the fact, and lead quicky to the experience of the locus of auditory sensitivity being ‘in’ the nose.

Inhalation, we saw, is necessary for olfactory perception; the intensity of experience arising from smelling a given stimulus rises and falls with the intensity of inhalation, even if we also adjust our expectations on the basis of the vigour of that inhalation, to support perceptual constancy; different smell-molecules, meanwhile, invite, and are better perceived by, different particular velocities of inhalation, and the same stimulus can smell different depending on the speed at which it is inhaled. Lastly, we modulate sniff duration dynamically, on the basis of stimulus attractiveness and intensity.

In this way, to imagine olfactorized audition, we first have to arrange that only while inhaling do we hear anything- that sound ceases entirely as soon as we breathe out, just as it does when we inhale through the mouth. To enjoy perfect silence, we only have to hold our breath. This would of course differ from normal forms of auditory silence, which strongly correlates with a silent, peaceful environment. Here, the same absence of auditory perception, in being contingent on our immobility, would not have any connotations of calm. Compare how the presence of aroma is to some extent undiminished when one is exhaling in a florist's.

Inhaling more vigorously should result in an increase in the intensity, or volume, of the sound; inhaling slower and deeper should deliver softer, longer sounds. Different sound-stimuli should invite different vigours of inhalation, and we should, in real time, adjust the vigour of our inhalation to increase the volume, intensity and clarity of pleasant sounds, just as we should put the volume down on unpleasant ones.

Identification of sounds should not always be immediate, as it tends to be in normal audition: we should have to interrogate many sounds with a series of sniffs, gradually honing in as we progressively categorize them. Imagine the refinement of perception of sound-identity over a bout of five dynamically modulated sniffs over the course of a second: pleasant high sound / pleasant sharp metallic sound / summery outdoor pleasant harsh sharp engine sound / pleasant summery outdoor pleasant lawnmower sound.

Smell and audition are not enormously different in their level of spatial acuity. Such similarity is reflected in the related strategies we employ when searching for the source of a sound and that of a smell, in the absence of reliable visual cues. Think of when a mobile phone is ringing from somewhere within the cluttered mess of a bedroom, and how one can wander around, dipping one's head here, lifting a duvet there, paying attention to the rising and falling of the intensity of the noise, until one eventually zones in on its source. This is almost exactly what we do when we are trying to locate the source of a smell, minus the sniffing. To the extent that audition is more spatially acute than olfaction, it is because of its temporal acuity.

Audition is the most temporally acute of our modalities, whereas smell is the least. Audition's high temporal resolution consequently allows it a more dominant role in informing us of events in the world. For instance, when one's keys fall unseen out of one's pocket as one is cycling, the sound of them clattering onto the road will often alert one to what has happened; olfaction has no such ability to alert us to sudden events in our vicinity.

To olfactorize audition, then, we need to take steps to lower its temporal resolution. Leaving aside the time it takes a smell-plume to reach us from an object, the lower limit to the rate at which one can smell different sounds has to be the time it takes to exhale and then re-inhale sound-molecules laden air: on average on the region of a couple of seconds. The sounds we sniff, then, should persist for at least a second or two to mirror this slowness. The typical intensity of these sounds should, like with smell, rise and fall smoothly, and have a somewhat indeterminate beginning and end.

Speech-perception would be inconceivable in such a leisurely modality: there could be no clear order to the syllables in a word. But our olfactorized audition should not be entirely temporally featureless. There should, for instance, be an evolution in the notes of the sound that come into consciousness in the course of an inhalation: as the smaller, lighter, higher, sounds percolate first through the mucoid film we have to imagine over the nasal ear.

As we listen to an excellent glass of wine, its lighter sounds should emerge first, and in slow, indeterminate steps, lower sounds should be teased out in the course of our inhalation. The onset and offset of individual notes within this olfactory experience should be only vaguely placeable in time, the ensemble smooth.

3.1.3. Intramodal factors

We saw that smells relate to each in on the order of 50 dimensions, according to conservative calculations. How can we imagine this dimensionality into sound-space?

First of all, we must note that smell has no equivalent to pitch in audition, which places any tone in clear relation to other tones in a space of relative dissonance and so on. For audition to be olfactorized, we will thus have to eliminate our sense of pitch, which we can crudely accomplish by imagining that the world is monotonous.

In this monotonous environment, a rough auditory equivalent of smells may perhaps be the timbres of different instruments. Consider those of a trumpet, a violin, a choir, a clarinet and an oboe. Each is distinctive, some appear related; but we cannot easily describe them except in general terms how they differ from each other, being unable to pick out specific features of the sound-wave, for instance, to articulate the differences clearly. The timbres of different instruments are thus, like smells, ineffable, and they are moreover highly affective, a further point of similarity.

This tentatively suggested equivalence may also help to install olfaction's synthetic tendencies into hearing: when we listen to a flute and a trumpet and a violin playing the same note simultaneously, the ensemble has an experiential character that is not to be simply added together from the constituent tones.

The analogy between timbre and intra-modal olfactory quality calls for substantial elaboration where we consider the colossal variety of different smells that we can distinguish, estimated at 10,000, as against the relatively smaller number of distinguishable timbres, perhaps 500. Moreover, many of the differences that we can detect in the timbres of, for instance, musical instruments, depend on fine temporal features at the beginning and end of a given note. Consider how one can distinguish a long note played on a violin as against one played on an oboe far more easily if one hears the its onset and conclusion, and not just its middle.

But our olfactorized audition would not be able to avail itself of such fine temporal clues, being too slow: and we should similarly outlaw other distinguishing features of timbre that depend on fine temporal detail, such as vibrato. Our smelt sounds should not only all fall on the same note, but they should also be relatively temporally featureless, hummed as opposed to articulated noises.

All in all, then, olfactorized auditory perception should be capable of distinguishing the timbres of a-tonous temporally featureless sounds. But it should also give rise to a vast field of possible distinctions, equivalent to being able to tell the difference between each of an orchestra of ten thousand original instruments.

3.1.4. Behavioral factors

Olfaction, too vague to coordinate fine motor practices, seems particularly to play a role in determining our affective reactions to foods, people and threats. Audition, by contrast, is a great alerter, and plays a dominant role in communication, too.

We have seen that speech-perception would be inconceivable in a modality as slow as olfactorized audition- and this is just as true for any fine-grained discriminations that audition typically allows us to make. Instead, in order truly to olfactorize our audition, we must imagine using our new modality almost exclusively in the evaluation of the (un)attractiveness of foods, people and biological entities; and we should not forget to bless the modality we imagine with a peculiar mnemonic power. People and foods and places should each have a soft hum, only audible when we inhale in appropriate proximity. Some hums would be inherently arousing, others should immediately cause an aversive reaction, and others should stimulate our appetite.

3.1.5. Summary of Olfactorized Audition

Let us quickly summarize the sorts of changes that must be imagined if we are to take seriously the challenge of imagining audition with olfactory structure.

Olfactory stimuli must hang on the air, intermingling massively; olfactorized sounds must be slow, soft, synthetic and sniff-dependent; they must invite and reward different speeds, numbers and durations of sniff; they should resemble the pitch-less timbres of 10,000 distinguishable instruments, shorn of any revealing temporal features; that should be perceived from the nose and be incapable of guiding fine movement; each such sound should invoke diverse discriminatory and affective activity, particularly in relation to their dominant sources: foods, people and biological threats.

We would suggest that when audition is made so rigorously to imitate olfaction, it becomes vividly smell-like in imagined feel.

Whether or not intuition tells the reader that sound sensations have become smell sensations in these imaginings, it seems difficult to argue that they have not been utterly dissolved. One need only try to retain normal sound 'sensations' within imagined use of such olfactorized audition: one is left with nowhere to place them where they will not defy the spatiotemporal structural limitations and possibilities imposed by olfactory imitation.

Whichever sound experience one attempts to include, whether it be an echo, a chirp, the jangle of keys, the murmur of an audience, the bleep of a fire-alarm or the whisper of a voice, one inevitably appeals to just the dynamical and structural aspects of the modality that no longer exist. Even just by ruling out pitch and high temporal definition, one eliminates the dimensions along which these sounds are distinguished, and so one eliminates the possibility of their differing- and so existing perceptually. Olfactorized audition would render Prinz’s fire-alarm indistinguishable from a whispering voice: sensory significance goes deep.

Add to this situation that auditory perception should now depend upon and be modulated by sniffing, physical proximity, specific prior experience and deep emotiveness while at the same time permitting fine differentiations, and the notion that ‘sound sensations’ can be commuted into olfactory perception comes under such pressure as to become untenable. That is, too many of the properties characteristic of sound can no longer be imagined to remain in place, squeezed out as they are by the properties of smell.

In this way, we urge that the dependence thesis is supported by this thought experiment.

3.2. Smells becoming colours

According to the dependence thesis, smell-experience should exhibit a similar flexibility. For instance, it should be possible, using a similarly detailed imaginative technique, to describe a process whereby an odour-experience, <u>placed within a spatio-temporal context more typical of colour</u>, gives up all of its olfactory quality, exchanging it for chromaticity.

The following thought-experiment aims to assist the reader in evaluating the plausibility of this rather different prediction of the dependence thesis, then: that should smelling be able to assume the right physical, functional, sensorimotor and intra-modal relations, we would 'smell' 'colour'.

<u>3.2.1. A survey of the spatiotemporal conditions of colour-perception</u>

Experienced olour seems to be determined by the way that an object's surface changes the ambient light, selectively absorbing and reflecting different portions of the spectrum of light.

Experientially, colour appears to us always already within the manifold of a spatially extensive visually perceived scene. We always thus experience colour occupying at least some amount of visual space. The spatial and temporal precision of colour, like other seen aspects, is of a very high resolution: we can make out extremely detailed shapes that are coloured, and we can see colours change relatively rapidly. Colour and smell have some things in common: both contribute disproportionately to processes of object identification and evaluation, and both are strongly affective.

3.2.2. Turning smells into colours

In order to imagine smell in the place of colour, we will first need completely to eliminate normal olfaction, so as not to confuse things; and, next, to establish a standard kind of visual manifold, but stripped of its colour-content. This should be simple enough, for we all have considerable experience observing black and white films, and indeed our visual experience also tends towards colourlessness in conditions of low lighting[3].

We must then elaborate this black-and-white vision with smell, imitating as exactly as we can the way in which colour occurs within and elaborates upon the rest of vision. As we fixate different objects and surfaces, then, we need to replace the detection of colour that would normally accompany such fixation with the detection, instead, of smells. For the moment simply imagine that we experience smell whenever in good light we fixate a surface, and that the identity of the experienced smell depends systematically on the reflectance properties of that surface.

Note first of all, because of the alacrity of eye movements, that this will require smell to have a temporal resolution far higher than that which it normally enjoys, and a spatial resolution to match (for the moment, we can borrow this entirely from the acute spatiality associated with non-colour vision).

[3] Had we not worried about complicating our text, we would, more correctly, have specified in the main text that we are often talking about 'hue' when we are talking about colour. We hope that what would in another context be an imprecision does not bear on the points we argue for here.

Imagine a blue surface, a book, against a white background, some shelves. Assume for the moment that blue corresponds to the smell of paint, and that white is odourless. In this situation, when we fixate the white background to the left of the book, we should experience no smell whatsoever. At the moment we then move our eyes onto the blue book, however, we should with perfect immediacy smell paint in all its fullness. This visuo-olfactory experience should of course be entirely de-coupled from our patterns of breathing.

Wherever we rove our eyes over the surface of the book's spine, the smell of fresh paint should accompany us evenly and consistently, shifting in intensity only in response to light and shade effects. The moment our eyes stray form the book to the white shelf behind, though, odourlessness should of course resume.

Were such an ocular-motor-olfactory correlation to obtain, one thing of which we can be very confident is that the smell of paint would in fact come to be localized on the surface of the book. A great body of evidence from the paradigm of multi-sensory integration in psychology has shown that where a 'sensation', typically auditory or tactile, consistently co-varies with a visually perceived event, vision, the modality with the greatest spatial acuity, tends to dominate the "localization judgement" of the combined stimulus. This thus typically places the sound or tactile event in the environment. (e.g. Botvinick and Cohen (1998); see Spence (2007) for more on this rich area of research). This would most probably happen with smell[4]. Indeed, spatial

[4] Although the current state of technology probably does not permit implementing this visuo-olfactory contingency, an audio-visual analogue probably is possible. This strikes us as an experiment well worth doing: to engineer a system whereby the fixation of objects

referral of smells is one of the interesting features of taste: an experience becomes subjectively located in the food in our mouths, despite being largely determined by retronasal odours (Auvray and Spence, 2008).

So let us take it as read that we experience smell on the surface of any object that we happen to be fixating, and that the identity and intensity of odor so perceived is minutely responsive to the exact target of our eye-movements. Next let us explore the rich behaviours that would be enabled in complex environments if olfaction indeed possessed this spatiotemporal acuity and consummate integration with vision.

Extending the example of the bookshelf, let us now add a few hundred other volumes. For simplicity, imagine these other books each have one of only four possible surface-reflectance properties, corresponding to the four primary colours of red, blue, green and yellow. And let us arbitrarily say that 'red' books smell like strawberries, 'blue' ones like paint, 'green' ones like a meadow and 'yellow' ones like scrambled eggs. (We will return below, briefly, to the question of how one would more responsibly map smells onto colour space).

With smells standing in for absent colour, recall, the visual odour we would at any point be experiencing should be entirely contingent upon the surface-reflectance properties of the book that we are currently fixating with our otherwise black-and-white vision. First, note that as we flick our eye around the shelves, smell-experiences

viewed in black-and-white should result in the immediate presentation of sounds whose features, whether pitch or tone, correspond in some way systematically to the surface-reflectance properties of the object. In this case, too, we would predict that after a period of training, sound would come to be perceived, as colour is, on the surface of objects in the external world.

should arise and disappear with a frequency that would be bewildering were the smells not so reliably tied to the differentiated spatial locations being serially fixated. Not only should every object instantaneously express its smell on being sighted, allowing for rapid and precise differentiation, but an intriguing range of abilities should be characteristic of this form of olfactory vision.

Consider, for instance, how we should be able to exploit our ability selectively to attend to particular chromaticized odors as a means of seeking out particular books on these crowded shelves. With our olfactory vision, when seeking a book that smells of scrambled eggs, we should be able selectively to attend to that distinctive aroma, with the result that all books with such an aroma should immediately leap into salience. Even where there is just a single eggy volume among thousands of other distinct visually perceivable smells, we should be able to localize the source in an instant by attending appropriately.

Colour also furnishes and extends our abilities to perceive shape. If, with our bookcase example, chocolate-smelling volumes were so arranged as to form a rough circle on the shelves, we should immediately notice this form standing out against the background smells. Extending, for a moment, the range of examples, consider how we should be able to use smell for shape perception even to the point of face-recognition; we should be able to smell fast moving objects and identify them by their olfactory colour; and we should be disposed to have the visuo-olfactory experience of such things as fireworks displays and tropical flower-beds.

We can ask: are these very precise, highly spatio-temporally structured smells, that are grounded in normal visuospatial perception, that allow such things as detailed shape-perception, parallel search in a richly structured environment and differentiation at a distance of otherwise visually identical objects, phenomenologically smell-like? Would smell be smell, when perceived exactly on the very surface of the objects around us, independently of all inhalation?

Certainly, there's little chance of success in mapping any of the familiar descriptions of smell to this novel modality. There is nothing intangible, vague or structureless about the qualities that one would perceive on the surface of the objects; nothing here is floating free. If one woke up with this ability having been installed into one's mind overnight, it is improbable that one would guess that it had been knitted from olfaction. Were all these spatiotemporal features in place, it seems more likely that one would simply think that colour had got the heebie-jeebies, that it had lost its internal coherence. We suggest, that is, that the only aspect of the experience that would distinguish such olfactorized vision from familiar colour-experience, would be the lack of consonance in the intra-modal differences between the experiences: which would render these 'colours' otherwordly in their variability and inter-relations.

How would one impose on smell space the intra-modal relations that occur in colour? The challenges are acute: the disparity in receptor-repertoire (four-hundred in the case of smell, three in that of colour) and dimensionality (fifty versus, at best, a few) render an attempt at transformation an intimidating prospect.

Despite the difficulty, the way that one would go about imaginatively reducing or reconstituting smell-space so that it expresses the inter-relations of colours, is relatively clear. We would have to find smell equivalents for the primary colours of red, blue and green, and probably one for yellow as well. We should then attempt to re-work our associations for each of the selected smells so that they gain all the relations of opposition, admixture and relative warmth that hold between primary colours, and none of those that characterize the smells alone. Let us take just two examples, first of all a positive one: where our red- and yellow-equivalent smells are mixed, an 'orange' smell, one that is similar to and intuitively between both, should arise; and for an example of what would have to be removed, on the other hand: when, for instance, (arbitrarily) swapping in the smell of 'paint' as our olfactory equivalent for 'blue', we would have to take care not to carry over associations of similarity and difference that obtain between the smell of paint and related smells, such as those of rubber, vinegar and glue, that do not boast any helpful equivalents in colour-space, that cannot map to colours whose relation to blue is as these smells' relation is to paint.

These difficulties flow from the general one that a great many connections in olfactory space would have to be undone, as the mammoth network of context-specific, experience-dependent, multi-dimensional relations is pared down to a core of colour. To us, the existence and intractability of these difficulties ultimately manifest once more the dependence of the character of experience on its structural features.

4. Conclusion

Philosophers have on occasion taken smell-experience to exhibit a phenomenal quality so rich, vague and intangible that they have been quite at a loss to relate it to the candidate physical events -sniffing, neuronal processing and so on- that might be thought to produce it. We would argue on the basis of the foregoing thought experiments, that there is in fact good reason to suppose that smell-experience is precisely dependent on the structures of olfaction, and so "without remainder". That is, it would feel different if any of a large number of structural features of the modality were to be altered. If smell were divorced from patterns of breathing; if it had a spatiotemporal acuity capable of coordinating complex action; if it played no affective role in our lives; if it were capable of fewer, or different, distinctions; if it was tied to different sensorimotor conditions - in all these cases and more, smell phenomenality would be radically altered. Each of these changes would have widespread consequences for the uses to which the modality could be put in different situations. Where we make a concerted attempt to imagine such transformed capacities it just does not seem possible to sustain qualitatively identical smell experiences in what we are imagining. We are aware that it is inevitably possible for it to be claimed by a doubter of the dependence thesis, that there is some aspect of olfactory experience that would remain unchanged through the modifications imagined. We suggest, though, that where any such objection is proposed, it is reasonable to expect that it be expressed to the level of detail and explicitness that we have tried to pursue in our thought experiments. That is, it should specify what aspect of phenomenal quality is thought independent, and it should show how, in for instance the imagined transformation of olfaction into another modality, such a quality would remain unaffected. It is worth noting that in our thought-experiments, many structural factors, such as inspiration, that seemed prima facie irrelevant to olfactory phenomenality turned out under this kind of examination to present intimate links to it.

Rather than further elaborating this proposal, or anticipating objections to it, let us make a procedural observation. It relates to a tendency in the philosophical literature on consciousness to objectify experiences; to seek *within* them the source of what distinguishes them inter- and intra-modally; to think of sensory experiences such as that of smell as packaged into 'sensations'. On this mode of thought, we encounter the smell as an object: as something that stands apart from us, occupying some amount of (mental) space. In so doing, we tend to imagine that its existence and character are somehow independent of us. When we conceive of the character of experience like this, inevitably it is obscure how all the structural features which we propose as relevant to smell phenomenality can possibly play the role we think they do in producing it. For those structural features cannot, and logically do not, belong 'in' sensations qua independent qualitative objects. They inseparably depend on the reactions and dispositions and capacities of the person who is doing the experiencing. Such features are relational, and frequently temporal, in nature: they bridge the gap between experience and experiencer.

Specifically, consider how none of the following factors, on which we take smell experience to be dependent, can readily be imagined as present 'within' (the space of) a smell-sensation: the other smells that one is capable of discriminating, and their relations to this one; the way this particular smell invites and rewards particular patterns of inspiration; the way it enables the guidance of some forms of action and not others; the way it stimulates our appetite and our memory; the way it is relevant to the evaluation of some classes of object but not others.

We would like to propose that a perhaps more fruitful way of considering a smell experience than approaching it from the outside and look within, is instead to clamber inside, so to speak, and look outwards. Rather than thinking of a particular smell-experience as an autonomous source of phenomenal quality occurring in a neutral subjective perspective, that is, we propose instead that we should think of it *as* a subjective perspective, or at least as a form that a subjective perspective can assume. To stop eyeing and begin attentively smelling one's coffee is, on this view, to assume a perspective on the world; it is to be exposed to a wholly different constellation of constraints, engagements and possibilities.

A conspicuous turn in philosophy of mind and cognitive science which has similarly emphasized the subject's perspective, has been that towards enactive, embodied approaches to experience. Theories such as the sensorimotor contingency theory (O'Regan and Noë 2001, Myin & O'Regan 2002, O'Regan, Myin & Noë 2005), or the work of Thompson (e.g. 2007), stress, broadly speaking, that "experience is something that we do"; they emphasize the role of a subject's embodied and temporally extended interaction with the world as the basis for different forms of perceptual experience.

Each of the four structural dimensions whose relevance we have stressed -the physical form of the olfactory stimulus, the sensorimotor contingencies at play, the space of intramodal difference and the functional role that olfaction plays in our lives impact, in different ways, upon a person's possibilities and propensities for action and interaction in a given olfactory situation. This would seem to indicate, then, that a broadly embodied account of odour-phenomenality is a reasonable prospect.

On the one hand, it is clear that the physical character and distribution of the stimulus, as well as the related patterns of sensorimotor contingency that it offers, directly influence the forms of action and interaction enabled by it, so that the first two of our four structural elements naturally favour an embodied approach to olfactory feel. O'Regan and Noe's (2001) claim that experience is based in "practical mastery of the patterns of sensorimotor contingency", for instance, would seem well poised to account for the influence of these two factors on smell phenomenality.

While acts of sniffing and bodily movement may contribute richly to smell phenomenality, we also have to pay attention to the learning-dependent, context-specific, affective influences that olfaction has on our behaviour: and in these respects the sensorimotor theory is lacking. The intra-modal and functional structural factors in olfaction undoubtedly call for a more contextually and temporally rich account than one that would merely treat the patterns of action and interaction that are, given one's body and the physical stimulus, possible at a given moment.

Consider the aroma of fresh-roast coffee as against the scent of a rose. To attend to the smell of coffee is for a person to commit herself to negotiating a particular, object-specific space of discrimination; for her to enter an as of yet merely possible, but eminently reachable, world in which she sips desirously to anticipate tastes, textures, temperatures and delayed stimulative properties; it is to manifest an emphatically nonspatial form of active interest in her environment.

To smell a rose has its own, quite distinct, context-specific discriminatory demands, along with their own modes of associated action and affect. An account that wishes to capture the differences between what it is like to smell a rose as opposed to smelling coffee must be able to speak to inflections to the subject's situated activity on multiple time-scales, not just at the level of proximal sensorimotor interaction. We need a framework encompassing all of the diverging ways in how these two stimuli dispose us, on the basis of past experience, to elaborate the ongoing process of discrimination, to act and feel and intend differently over time periods that well exceed that required for merely identifying the stimulus.

Such a richly contextual, temporal view would hopefully make it self-evident that it is no more possible to trill the experience of the smell of coffee and that of a rose, than it is to switch in a second from the engaged perspective of someone in meditation to that of someone dancing the tango. Neither activity, and neither smell, would be what they are if capable of such capriciousness.

Acknowledgments

The research of both authors was sponsored by the Research Foundation – Flanders (FWO - project "Senses as tools. A Philosophy of the Sensory Modalities"), and by the Research Council of the University of Antwerp (BOF-NOI project "Visual Imagery as Perceptual Activity"). The authors wish to thank Jan Degenaar, Bence Nanay, Kevin O'Regan, John Sutton and Karim Zahidi for insightful discussion and feedback.

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