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Smelling x as y? On (the impossibility of) multistable perception in the chemical senses

Nicola Di Stefano [a,*], Charles Spence [b]

[a] *Institute of Cognitive Sciences and Technology, National Research Council of Italy (CNR), Rome, Italy*
[b] *Crossmodal Research Laboratory, University of Oxford, Oxford, United Kingdom*

A R T I C L E I N F O

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A B S T R A C T

Multistable percepts are intriguing phenomena whereby an ambiguous sensory input can be perceived in one of several qualitatively different ways. In such cases, people can switch their attention to perceive the stimulus in either way, though they typically cannot maintain both interpretations in awareness simultaneously. The abundance of evidence demonstrating multistable perception in the visual and auditory modalities can be contrasted with the scarcity, if not absence, of studies reporting similar phenomena in the chemical senses (primarily olfaction and gustation), prompting an intriguing question about this apparent qualitative difference between the senses. This paper seeks to address this question by first briefly reviewing multistable perceptual phenomena in vision and audition to underscore their defining features. We then assess the limited body of research that has occasionally linked multistability to the chemical senses. While a few studies suggest loose analogies between olfactory perception and visual or auditory multistability, no compelling evidence exists for such phenomena in taste. We argue that this absence is unlikely to be explained by any single factor. Rather, it appears to stem from a confluence of constraints, including the lack of spatio-temporal structure and intrinsic dimensionality in chemosensory stimuli, as well as their distinct evolutionary functions and cognitive framing. Together, these factors may help to explain why multistable perceptual experiences seem not to emerge in the chemical senses.

1. Introduction

Bistable perception refers to the phenomenon whereby a particular sensory input can lead to two qualitatively distinct perceptual experiences that typically alternate in the mind of the observer. This occurs when the sensory information presented to an individual is ambiguous and compatible with two (or more) different percepts. In these cases, scholars often use the term ‘multistable perception’, as opposed to the way in which we normally perceive objects in the real world as stable and unchanging. Many classic examples of bistable perception have been reported in the visual modality, such as the famous Necker cube or the Rubin vase, where the viewer’s perception spontaneously flips between different percepts without any change in the actual stimulus (see Fig. 1).[1]

While vision provides some of the most intuitive, and certainly most widely discussed, examples of bistable perception, putatively

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* Corresponding author at: Institute of Cognitive Sciences and Technologies, Via Gian Domenico Romagnosi 18A, 00196 Roma, Italy.
E-mail addresses: nicola.distefano@istc.cnr.it (N. Di Stefano), charles.spence@psy.ox.ac.uk (C. Spence).

[1] Though, in the case of the face-vase example, it has been suggested that a shift in the spatial focus of visual attention may precede the change in perception (Baylis & Driver, 1992; Mazza et al., 2005).

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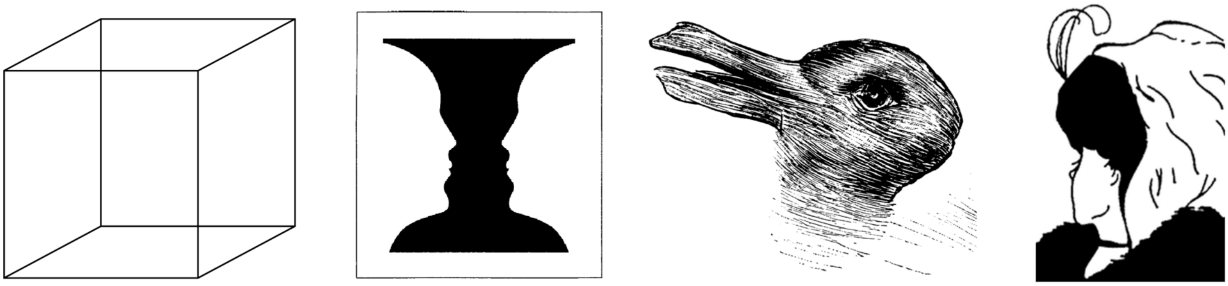

Fig. 1. Classic examples of bistable perception in vision. From left to right: Necker Cube, Rubin Vase, Duck-Rabbit, Old Woman-Young Lady.

similar experiences have been reported in other senses, such as, for example, audition (see Gallace & Spence, 2011; Schwartz et al., 2012). However, bistable perception appears to be less common, if not entirely absent, in the chemical senses, with no conclusive evidence of spontaneous reversals occurring in the case of olfactory and gustatory perception (see also Spence & Youssef, 2016). This raises the following intriguing questions: Why should these senses be somehow unique in relation to the phenomenon of bistable perception? Does the rarity of multistable experiences in the chemical senses reflect more than just a "visual" bias in research (e.g., Hutmacher, 2019)? Or could it be taken as pointing to a more fundamental reason as to why such experiences might inherently differ from those involving the spatial senses? Could factors relevant to experiencing multistable percepts, such as attention, be allocated differently, or attention-switching occur more slowly, in the chemical senses as compared to the spatial senses (e.g., Spence, 2019)?

In this paper, we aim to address these questions by first briefly discussing bistable perception in the most studied domains, namely vision and audition (**Section 2**). We then move on to examine the limited research available on bistable perception in the olfactory modality, reflecting on the notable absence of evidence of "tasting-as" experiences (**Section 3**). Thereafter, we highlight a number of key factors that might account for the distinction between the spatial and chemical senses as far as bistable perception is concerned (**Section 4**). We conclude by posing a number of open questions raised by the review of the literature and suggesting potential directions for future research in bistable perception (**Section 5**).

2. Bistable perception in vision and audition

When exposed to ambiguous images such as the ones depicted in Fig. 1, observers initially perceive one interpretation (e.g., the rabbit). After a few seconds, they may switch to the other (e.g., the duck), and this alternation typically continues. Crucially, throughout this process, the visual stimulus and retinal stimulation remain essentially unchanged; what shifts is the interpretation of the sensory information (see Necker, 1832; and Attneave, 1971, for a review; Sterzer et al., 2009, for a neurophysiological account).[2]

Researchers have tried to group bistable visual images into various categories based on the factors that trigger ambiguity. The ambiguity of some figures relies on the alternation between what is seen as constituting the background/foreground figure, where the perceived one acquires the connotation of the figure while the other is relegated to the background (e.g., the Rubin vase, see Fig. 1). Others imply a perspective change (or change in the assignment of the labels to the principal axes), with the object remaining the same (e.g., the Necker cube, see Fig. 1). Finally, others imply alternating between two percepts with different semantic contents based on the reassignment of the principal axes of the object (e.g., back-front in the duck-rabbit and old woman-young lady images, see Fig. 1; see Marr & Nishihara, 1978).

Other classifications can, for example, be based on the number of possible percepts of the image and whether the stimulus is shown statically or in movement. The former criterion highlights the existence of bistable and tristable stimuli (Long & Batterman, 2012; Naber et al., 2010), while the latter criterion will result in the distinction between static and dynamic ambiguous images. An example of the latter is "The silhouette spinner", a video showing a bistable image in movement where the silhouette of a dancing woman can be perceived as rotating either clockwise or counterclockwise (Liu et al., 2012).[3] Finally, the possibility of perceptual reversals emerges, where reversibility results from a shift in the direction of movement (Jackson et al., 2008).[4]

While these classification schemes help clarify the variety and structure of ambiguous stimuli, they do not, in themselves, explain how or why perception flips between interpretations. This brings us to a central question in the study of perceptual bistability: how is perceptual ambiguity ultimately resolved? Many researchers have argued that the perception of ambiguous images operates similarly to how the visual system functions normally (Long & Toppino, 2004, for a review). Typically, the brain selects the most probable interpretation of a visual scene, and this usually results in a single, stable, perceptual interpretation. For example, a distant large object

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[2] Psychologists have conducted research to measure the frequency with which such spontaneous reversals take place and find that, in the case of the Necker cube, it oscillates back-and-forth every 2.5–3.0 s, on average (see Pöppel, 1988, pp. 55-58; Pressnitzer & Hupé, 2006).

[3] In this case, stability refers to the 3D object that allegedly generates the 2D rotating image.

[4] "The dress" provides another example of a static ambiguous stimulus. It refers to a photograph of a dress that sparked widespread debate over its colour. Viewers were divided, with some people seeing the dress as blue and black, while others saw it as white and gold. The intense debate highlighted significant individual differences in colour perception and became a popular topic for exploring how our brains interpret visual information, and colour constancy in particular (e.g., see Brainhard & Hurlbert, 2015).

or a nearer small object can give rise to the same projection on the retina. In this case, the ambiguity is resolved effortlessly, that is, perceivers are not even aware of there being any ambiguity. Ambiguous or bistable figures, however, make this interpretive process – which typically occurs rapidly and effortlessly – more apparent due to multiple mutually exclusive interpretations triggered by the same retinal input. According to this view, the shift between interpretations is driven by relatively automatic brain processes, which are critically dependent on the stimulus features and largely independent of higher-level cognitive processes.

At the same time, however, some researchers have proposed a more cognitive view, challenging the automaticity of figural reversals and emphasizing the observer's active role in processing ambiguous patterns. This perspective highlights the importance of internal resources such as attention, learning, and expectations in interpreting the retinal input. According to these explanations, perceptions arise from hypotheses based on both stored knowledge and sensory data (e.g., Gregory, 1974). When faced with ambiguous images, such as the duck-rabbit figure, two equally probable "hypotheses" emerge, which alternate, one with the other. The switch between percepts may even function as a strategy to test and eliminate the less likely hypothesis. However, the question of why the system 'abandons' one interpretation only to alternate between them remains open and intriguing.[5]

In addition to visual perception, occurrences of multistability have been also reported in the auditory domain. For example, being exposed to the repetition of certain speech sounds might result in the alteration of the verbal organization which abruptly transitions to other words or phrases, a phenomenon also known as the verbal transformation effect. Examples of this phenomenon can be obtained by repetition of 'say' becoming 'ace' or 'rest' which may shift to 'stress' or even 'Esther' (Warren & Gregory, 1958). A famous occurrence of an ambiguous word sequence is 'ice cream/I scream' (see Lee et al., 2020). In music, an example of perceptual multistability is the scale illusion (Deutsch, 1974, 1975; Radvansky et al., 1992), where two pitch-shifting melodies, one presented to each ear, are reorganized by the brain into coherent ascending and descending scale fragments. Rather than reporting disjointed inputs, listeners typically perceive two smooth melodic lines—high tones in one ear, low tones in the other—even though neither ear actually receives a coherent melody. Another case is the tritone paradox (Deutsch, 1986a, b), in which pairs of tones separated by a tritone are perceived as ascending or descending depending on the listener. These tones consist of complex harmonic structures lacking clear octave cues, making the direction of pitch change ambiguous and open to individual interpretation.[6]

The reviewed literature helps identify the conditions that must be satisfied, at least in vision and audition,[7] for bistable perception to occur (see also Kubovy & Yu, 2012; Schwartz et al., 2012), namely:

1) a stable (yet perceptually ambiguous) sensory input,
2) two possible alternative perceptions (or more than two in the case of multistable perception),
3) the multiple interpretations should be spontaneously triggered by the sensory stimulus,
4) the various percepts must be plausible given the sensory stimulus,
5) perception alternates periodically from one interpretation to another,
6) the various percepts cannot be experienced simultaneously.[8]

3. No conclusive evidence for bistable perception in olfaction and gustation

We now turn to the chemical senses, where research on bistable perception remains relatively scarce. Only a limited number of

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[5] The probabilistic account of bistable perception, rooted in predictive processing, might be also mentioned here. Such account frames perception as an inferential process where higher-level predictions are tested against sensory input, and mismatches (prediction errors) update beliefs via Bayes' rule (Weilnhammer et al., 2017). While effective in modelling perceptual switching, this account faces the challenge of explaining why perception feels deterministic. Block (2018) argues that although probabilistic processes may underlie perception, our conscious experience tends to reflect only the dominant interpretation—raising questions about how the brain resolves ambiguity while maintaining perceptual stability.

[6] It should be noted that the ambiguity likely occurs at somewhat different levels in the two cases. In the scale illusion, conflicting spatial and pitch cues lead listeners to prioritize pitch, resulting in the perception of coherent scale fragments across ears—an ambiguity in how information is organized across auditory channels, though the outcome is generally consistent across listeners. In contrast, the tritone paradox creates ambiguity at the level of pitch extraction, producing variable interpretations both within and between individuals. Similar perceptual ambiguities have been noted in other auditory, visual, and audiovisual contexts (O'Leary & Rhodes, 1984; Spence, 2015a).

[7] Some examples from tactile perception have been occasionally grouped with bistable phenomena, although they more properly concern perceptual rivalry or illusions rather than multistability. These cases typically do not involve spontaneous alternations between mutually exclusive interpretations of a constant stimulus, but rather a single illusory experience emerging from ambiguous or conflicting input. For instance, Carter et al. (2008) adapted the apparent motion quartet to a tactile setup using vibrotactile stimuli, showing perceptual alternations between vertical and horizontal motion—a case of tactile rivalry. Other somatosensory illusions include the cutaneous rabbit (e.g., Flach & Haggard, 2006; Geldard, 1975) and the thermal grill illusion (Craig & Bushnell, 1994), both of which elicit coherent but illusory experiences. See Gallace & Spence (2011) for a Gestalt-informed overview of such tactile illusions.

[8] These conditions help distinguish bistable perception from related phenomena like perceptual rivalry and perceiving-as (Pisarchik & Hramov, 2022; Safavi & Dayan, 2022). In perceptual rivalry, two distinct stimuli are presented to separate sensory channels, resulting in alternation rather than blending. Unlike bistability—which involves competing interpretations of a single stimulus—rivalry involves competition between two inputs. Both share key features: only one percept is experienced at a time, and perception alternates spontaneously. Unlike bistable perception, seeing/hearing-as typically involves cognitively-mediated interpretation layered onto perception. For instance, recognizing a tone sequence as an inversion of a theme requires inference and may not occur spontaneously. One can hear or even perform the sequence without perceiving it as an inversion. In contrast, illusions like the tritone paradox present as one percept or another without interpretive effort. Moreover, hearing-as interpretations are often unequal in salience and, once achieved, tend to remain stable rather than alternate, unlike bistable phenomena.

empirical studies have explored ambiguity in olfactory perception. However, some paradigms inspired by binocular rivalry in vision have been adapted to olfaction. In these studies, participants were presented with different odours to each nostril, and some reported alternating between the two percepts—an effect that has been referred to as 'binaral rivalry' (Zhou & Chen, 2009). As in the case of binocular rivalry, in this paradigm, the participant's perception may switch from alternately experiencing one odour and then the other, but not their mixture. Despite providing the first critical evidence of perceptual rivalry in the olfactory system, however, the study cannot be considered as demonstrating the existence of bistable perception, given that different stimuli, and not the same ambiguous one, are presented to each nostril.

A different protocol was used by Herz and von Clef (2001) to test the ability of verbal labels to create what the authors describe in terms of olfactory illusions.[9] To this end, they chose 'ambiguous' odorants[10] as olfactory stimuli, namely menthol, patchouli, violet leaf, pine oil, and a 1:1 combination of isovaleric and butyric acid. In the experiment, participants were presented with the odorants in two sessions separated by one week. In both sessions, they were exposed to the same set of five odorants in a random order, but each odorant was labelled differently, namely positively and negatively-valenced terms, in different sessions. The positive labels were breath mint, incense,[11] fresh cucumber, Christmas tree, and parmesan cheese, while the negative labels consisted of chest medicine, musty basement, mildew, spray disinfectant, and vomit. The participants rated the odorants for pleasantness, familiarity, and intensity (Likert scale, 1 = lowest, 9 = highest). Additionally, they were asked to provide some qualitative information, such as what the scent made participants want to do and/or how they would use it; whether it evoked a memory (and if so to briefly describe it); and what they thought it was.

The results revealed that participants perceived the acid combination, patchouli, and violet leaf to be different at each session. That is, as a function of the label provided an olfactory illusion was created almost 85 % of the time for these three odorants. The acid was the odorant most strongly affected by verbal context, changing from a mean rating of 5.06 when labelled as "parmesan cheese," to 1.68 when called "vomit." The same odorant was rated as significantly less familiar when given a negative label than when given a positive label. For intensity ratings, violet leaf was perceived as significantly more intense when labelled "mildew" compared to when it was called "fresh cucumber." These results suggest that the perception of certain ambiguous odours could be altered as a function of the verbal information accompanying the presentation of the odour.[12] It is noteworthy that the authors propose that these findings represent the first empirical demonstrations of illusions in the sense of smell.[13]

While this study showed that the same ambiguous sensory stimulus is perceived differently due to contextual changes, it cannot be considered a demonstration that multistable perception is possible in olfaction in the same way it occurs in vision. A couple of points should be mentioned here. First, out of the three items, verbal priming mainly impacted pleasantness, which is a subjective quality likely influenced by the source object associated with the odour. In contrast, more objective qualities, such as intensity, appear to be less affected by verbal labels. Second, the use of verbal labels suggests two distinct levels at play: On one side, the perception of odours, and on the other, the semantic information that is conveyed by the label. This differentiates Herz's and von Clef's (2001) study from bistable experiences, as the alternatives involve information that is perceived versus cognitively-driven, introduced by the experimenter through linguistic priming. This goes against one of the defining features of perceiving-as, that is, alternative interpretations should be rooted in perception, not generated/evoked cognitively (see also Cornell Kärnekull et al., 2021). Finally, as observed by Zucco and Job (2012), these findings can also be interpreted in terms of perceptual illusion, such as the lightness contrast illusion whereby the same gray patch placed on a black background appears lighter than an identical gray patch placed on a white background. However, the existence of olfactory illusions remains a matter of debate (e.g., Batty, 2014; Lycan, 2000; Stevenson, 2011; see also Todorović, 2018, concerning visual illusions).

Regarding gustation, the evidence in the literature is even scarcer. One could refer to anecdotal examples, such as wine-tasting experiences, where participants are invited to identify flavours like black pepper or bell pepper in a particular wine (and report clearly identifying those flavours only once they have been called out). Or consider chef Heston Blumenthal's two-flavoured ice cream (cinnamon and vanilla), which is perceived as one flavour or the other depending on the aroma (i.e., cinnamon or vanilla) inhaled in-between tasting the ice cream (Spence et al., 2017). However, the role of sensory, cognitive or semantic priming in these cases influences the perceptual experience, which contradicts the requirement that both percepts should be triggered spontaneously by the sensory stimulus.[14]

Some stimuli in olfaction and gustation are often labelled as "ambiguous" due to the different responses that they evoke in

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[9] Here, one could observe that the definition of a perceptual illusion is far from universal or clear, and the mere existence of two interpretations of the same percept is surely not enough to constitute an illusion (see Gregory, 1996; Zucco & Job, 2012).

[10] Herz and von Clef (2001, p. 382) define an ambiguous odour as one that lacks a fixed source but has at least two possible anchors with large differences in hedonic connotation from each other.

[11] Incidentally, empirical evidence suggests that incense is not universally perceived as pleasant across cultures (Ayabe-Kanamura et al., 1998).

[12] However, the same findings could also be interpreted as indicating that sensory discriminative perception remains unchanged in both cases, while the hedonic response varies. This distinction highlights that ambiguity can stem from the stimulus itself or from differences in how perceivers rate it. Additionally, an individual's perception of the same stimulus can shift over time—from x to y—though such changes often pertain to the hedonic attributes of the stimulus (e.g., coffee or alcohol, which may be perceived differently in childhood as compared to adulthood).

[13] In similar studies, controlling for experimenter expectancy effects or biases presents a challenge, as it can be difficult to determine whether any reported differences in olfactory perception reflect actual sensory variations or if participants are simply providing responses that they believe will align with the experimenter's expectations. Moreover, similar effects might be obtained from adaptation to the stimuli (e.g., in the case of vanilla/cinnamon ice cream, see Spence, 2022).

[14] Such cases could be also considered as examples of perceptual emergence.

different/same person(s). For instance, coriander leaf, is perceived by some individuals as fresh and citrusy, while others experience it as soapy or unpleasant due to genetic variations in olfactory receptors (Spence, 2023a). Benzaldehyde, which has an almond-like aroma, can evoke different sensory experiences depending on concentration and context: it may be perceived as pleasant and nutty in small amounts, reminiscent of almonds, but in higher concentrations or certain contexts, it can evoke an overpowering, synthetic scent that some find less appealing.[15] However, none of these examples qualify as instances of bistable perception, as the percept itself does not undergo any change over time within a single perceiver.

Other researchers presented their findings in terms of a “taste illusion”. In a study by Todrank and Bartoshuk (1991), for example, participants felt the taste of a substance while the experimenter applied it to the tongue in a sweeping movement originating from one side of tongue, reaching the tip and then ending at the opposite side. The results show that the taste of four different substances (sucrose, sodium chloride, citric acid, quinine hydrochloride) varies in intensity from the side to the tip, but then remained constant from the tip to the opposite side. Note that the term ‘illusion’ here refers to the unexpected variation in perceived intensity of the same substance as it moves around the mouth, rather than to genuine cases of bistable perception.

Finally, it is perhaps also worth mentioning a study by Youssef et al. (2016), which created a culinary version of the duck-rabbit illusion. A simplified version of the visual illusion was stencilled onto a plate alongside a ‘crispy dumpling’ made from confit duck and rabbit leg. However, the findings primarily relate to the influence of bistable visual information on flavour and food expectations, rather than to bistable experiences in gustation (or better said, flavour).[16] Meanwhile, Michel et al. (2014) presented an adaptation of the rubber hand illusion involving the tongue, which led to occasional mislocalizations of the origin of taste sensations. In sum, while these studies and anecdotes offer fascinating insights into how gustatory experiences can be influenced or even misled, they do not provide evidence for true multistable perception in gustation. Rather, they highlight related but distinct phenomena—illusions, priming effects, and contextual shifts—none of which meet the criteria of spontaneous perceptual alternation.

4. Why are there so few (unclear) cases of multistable perception in the chemical senses?

We now come to address the main question of this paper, namely, what makes olfaction and gustation unique with respect to multistable perception? In other words, one might wonder whether the reason for the rarity, if not absence, of multistable experiences in the chemical senses and trigeminal taste sensations, reflects nothing more than a lack of research in the field (perhaps linked to the often documented visual bias in research; Hutmacher, 2019), or whether instead there is a more fundamental reason as to why these perceptual experiences might be destined not to be experienced as in the case of the spatial senses.[17] In the following sections, we explore several structural, perceptual, and evolutionary factors that offer intriguing and plausible suggestions to help address the central question of this paper (see Table 1, for a summary).

4.1. Weak objecthood of odours and tastes

The literature has extensively explored the properties of olfactory objects, often in comparison with other sensory objects, mainly visual. In this respect, several authors converged, highlighting that olfactory perception exhibits a notably diminished degree of objectification relative to paradigmatic cases such as vision (e.g., Batty, 2012; Lycan, 2000; Keller, 2017).[18] Here, objectification refers to the psychological process whereby sensory qualities are treated as properties of external objects, distinct from the subject’s own mental states. While colours, shapes, and textures are experienced as belonging to external entities, such that these objects are tacitly conceived as retaining their properties, the attribution of smells to allegedly external olfactory objects remains comparatively fragile (Batty, 2011; Lycan, 2000; though see Millar, 2019).

One relevant factor impacting olfactory objecthood is the possibility to obtain varying perspectives on the same object, a key process in visual perception, where we can form anticipations and test expectations about how the same object would appear from different angles (see also Lycan, 2000). This mechanism is key to the formation of the notion of a enduring object that maintains its identity across shifting sensory circumstances. In contrast, olfaction does not afford analogous perspectival variation. The notion of obtaining different “olfactory perspectives” lacks clear meaning within the modality itself (Barwich & Smith, 2022). While an object may emit different volatiles from different parts, distinguishing these differences requires assistance from other modalities such as vision or touch (Richardson, 2013). Thus, smell alone does not provide the intramodal resources necessary for checking and refining perceptual objecthood.

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[15] Consider also the experience of exotic foods like durian, Époisses cheese, or freshly ground coffee, which can present distinct perception or chemical presentation depending on whether they are smelled orthonasally (through the nose) or retronasally (through the mouth). The stimulus itself presumably remains chemically essentially the same in each case, but the perception differs based on the route of entry (Rozin, 1982).

[16] Trigeminal sensations might also be mentioned here, such as pungency and piquancy, which are part of our chemical senses. Experiences of “hot” sensations could flip between thermal (temperature) and chemical heat. Additionally, instances where individuals confuse sour and bitter tastes, suggesting that while errors in classification may decrease with training, the nature of this confusion—whether it should be termed bistable or simply a slow switch—is uncertain.

[17] Interestingly, there appear to be no reported occurrences where observers experience bistable interpretations not regarding the sensory stimuli, but rather the sense modality that is involved (i.e., sometimes thinking the hear the stimulus, and then that they see it instead).

[18] However, even in the so-called higher spatial senses, such as vision and audition, the properties of perceived objects are not always stable or clearly defined (e.g., Turatto et al., 2005).

Table 1
Summary table. True multistable perception requires (i) a stable, yet ambiguous input, (ii) spontaneous perceptual reversals, and (iii) plausible alternative percepts based on the sensory data alone. Chemical senses (olfaction, gustation) largely lack these conditions due to structural, cognitive, and evolutionary constraints.

Sensory Input	Modality	Stable Perception?	Multistable Experience?	Typical Mechanisms
Ambiguous figure (e.g., Necker cube)	Vision	Yes (object constancy)	Yes (Necker cube, Rubin vase)	Perceptual ambiguity; spontaneous alternations based on attention/cognitive focus
Ambiguous sounds (e.g., “ice cream”/“I scream”)	Audition	Yes (auditory scene analysis)	Yes (verbal transformation, scale illusion)	Temporal integration; attention-driven reinterpretation
Single odour or odour mixture	Olfaction	Fragile (weak objecthood)	No multistability; only context-driven illusions (e.g., verbal priming effects)	Contextual modulation; memory and semantic associations
Single taste or flavour	Gustation	Very weak (minimal objecthood)	No multistability; only cognitive reinterpretation	Holistic processing; linguistic/conceptual priming

Moreover, olfactory experience is marked by phenomenal indistinctness. Unlike vision, which presents richly structured arrays of features, smell tends to offer an undifferentiated amalgam of properties (Aasen, 2019). Boundaries between different odour qualities are often blurred, lacking the crisp individuation that supports object-centered perception. This indistinctness is further compounded by the frequent conflation of smell and taste in everyday experience (Lycan, 2000). The contribution of retronasal olfaction to flavour perception, for instance, is routinely misattributed to gustation, demonstrating how olfactory phenomena are easily submerged under other modalities (Shepherd, 2012; Spence, 2015b, 2016).

The weak/lack of objectification is even more pronounced in the case of gustation. In the literature, virtually no comparable discourse exists concerning the attribution of objecthood to tastes. Taste perception lacks the informational richness, spatiality, and perspectival variation necessary to ground the concept of stable perceptual objects (O’Callaghan, 2008). As a result, the very idea of “gustatory objects” is rarely, if ever, entertained. Gustation is typically regarded as presenting mere qualitative states, without individuating external entities. This deepens the asymmetry between vision and the chemical senses and highlights the extent to which taste, even more than smell, resists objectification within perceptual experience.

An additional argument against the objecthood of odours/smells could be made based on the distinctive ways they are encountered through our sensory systems. First, unlike vision, which provides continuous and stable access to spatially bounded objects, olfaction and gustation are fundamentally structured around intermittent, active sampling of the environment. In olfaction, for instance, respiratory rhythms and sniffing behaviours regulate when and how odorants are perceived (Halpern, 1983). Similarly, gustatory experience relies on discrete acts of ingestion rather than constant sensory access. This episodic and interaction-dependent mode of perception undermines the continuous, object-centered mode that characterizes paradigmatic sensory modalities like vision.

Second, odours and tastes typically represent objects in transition rather than (more) enduring/stable entities. Smells often arise from processes such as decay, cooking, fermentation, or diffusion — dynamic states of material change rather than fixed, bounded objects. Consequently, olfaction informs us less about persistent, individuated objects ‘out there’ and more about transient, evolving processes occurring in the environment. Because of this, olfactory perception aligns less with the notion of discrete objecthood and more with the experience of ambient, processual phenomena. Together, the intermittent sampling and the dynamic, transitional nature of what is perceived make odours/tastes poor candidates for classical objecthood. They lack stability and continuous accessibility usually required for something to be categorized as a perceptual object in the philosophical sense.

The weak objectification of olfactory/gustatory perception has significant implications for understanding multistable perception in the chemical senses, offering fewer informational anchors for stabilizing discrete and distinct percepts. Given the lack of perspectival control, the phenomenal indistinctness of olfactory stimuli, and their frequent conflation with gustatory inputs, changes in attention, memory, or cross-modal cues can rapidly alter olfactory experience without the resistance typical of visual multistability. Similarly, gustatory experiences, heavily reliant on retronasal olfaction, are susceptible to shifts in perceived flavour identity. Thus, the structural weaknesses in olfactory and gustatory objecthood directly affect the dynamics and fluidity of (multi)stable perception in these modalities, challenging assumptions derived from visual models that are likely key to multistable perception.

4.2. *Lack of spatiotemporal structure*

The limited empirical research on the temporal structure of experience in the chemical senses (e.g., Obrist et al., 2014; Von Békésy, 1964) highlights questions about how percepts form in these modalities. While studies have shown that low-level, unconscious processing of gustatory information involves temporal coding (Hallock & Di Lorenzo, 2006), odours and tastes are not typically perceived as temporally organized stimuli. For instance, unlike audition, vision, or touch—which can readily encode temporal structures such as beat or rhythm—smell and taste lack this capacity. This limitation is likely due to the slower temporal resolution and the gradual onset and offset dynamics characteristic of chemical senses (see Di Stefano & Spence, 2025, for a recent review).[19]

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[19] For people to distinguish between sequentially presented visual, auditory and tactile stimuli, a conservative estimate for the minimum inter-stimulus interval is around 100 ms—much faster than any reported values for olfaction and taste (Di Stefano & Spence, 2025).

Regarding the temporal structure, Sela and Sobel (2010) observed that, whereas vision and audition consist of nearly continuous input, olfactory input is discrete, made of sniffs that are separated in time. If similar temporal breaks were artificially to be introduced to vision (or audition), they would induce ‘change blindness’ (or ‘change deafness’, see Eramudugolla et al., 2005; Gaston et al., 2017; Gregg & Samuel, 2008), that is, a loss of attentional capture that results in a lack of awareness to change. Whereas “change blindness” is an aberration of vision and audition, the long inter-sniff-interval renders “change anosmia” the typical condition in which humans smell odours. The authors suggest that these breaks in olfactory sampling result in the inability to spontaneously detect less than drastic changes in the olfactory environment. Impaired olfactory change detection may in turn result in poor attention to olfaction.[20]

Complicating matters somewhat, the perception of olfactory stimuli is uniquely intertwined with memory because odours are not statically in front of perceivers; they evolve over time. As happens with sounds, parts of an odour experience are transient, existing only in memory once the immediate scent fades. This makes olfactory perception both a present and retrospective process, where past “impressions” of the smell contribute to our ongoing experience of it. This temporal aspect means that our perception of complex scents is cumulative, informed by earlier stages of the scent and thus shaped by memory, context, and mental imagery.[21]

As for spatiality, while olfaction provides crucial spatial information about the environment—such as detecting potential dangers—odours and flavours lack *intrinsic* spatial structure (e.g., Lycan, 2000). As noted by Auffarth (2013), the relative lack of spatial topology in olfaction compared to other sensory modalities suggests that the direct relationship between stimulus and percept, typical in vision and audition, does not apply to smell. This likely implies a different form of information processing in the olfactory system. Sela and Sobel (2010) concluded that, in contrast to the excellent spatial abilities in vision and audition, humans have only rudimentary spatial abilities in olfaction.[22] Thus, humans do not have a spatial arena in which to direct olfactory spatially-selective attention, and this renders olfactory attention profoundly different from visual and auditory attention, hindering also stimulus-space based attention (like the cocktail party effect in audition).[23]

4.3. *Dimensionality of stimuli and perceptual space*

The dimensionality of gustatory and olfactory stimuli has long been debated in the philosophy and psychology of perception (e.g., Le Guérer, 2002). While humans can recognize a wide range of olfactory stimuli, they often struggle to describe them using a consensual set of perceptual dimensions.[24] Instead, people tend to rely on idiosyncratic strategies, such as referencing odour sources or using gustatory terms (or other sensory features) metaphorically. Although individuals may be able to compare smells when provided with a specific feature, such as spiciness, there is no agreement on how many dimensions are needed to represent the olfactory space. In fact, the dimensionality of olfactory datasets in the literature can be surprisingly high. The complexity of olfactory spaces is highlighted in studies like Koulakov et al. (2011), which reveal the intricate representations required to map the multidimensional nature of smell (see Fig. 2).

Currently, there is no universally accepted system for odour classification (Auffarth, 2013). Various studies using different data, statistical methods, and descriptive approaches suggest that odours can be grouped by perceptual similarity (e.g., Civille & Lawless, 1986; Zarzo & Stanton, 2009), and some categories are consistent across cultural boundaries (Chrea et al., 2005). These categories include smoky, camphoraceous, fruity, herbaceous, resinous, earthy, and sweet. The concept of “primary” or “basic” odours—similar to primary colours from which all others are derived—has been proposed (e.g., Weiss et al., 2012). However, whether compositionality alone is sufficient to define basic odours remains speculative, and the idea lacks a clear, testable framework.

In contrast, the dimensionality of auditory and visual stimuli is relatively stable and more widely accepted. Visual stimuli can vary along dimensions such as colour/hue, shape, depth, motion, and texture, while auditory stimuli vary in pitch, loudness, timbre, duration, and spatial location. These well-defined dimensions allow for multiple interpretations of a single stimulus, facilitating

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[20] However, some researchers challenge this interpretation. Wilson (2023), for instance, has argued recently that olfactory experience possesses a distinctive temporal structure that should not be directly compared to vision or audition. Any temporality present in olfaction or gustation, however, could not be considered analogous to that in audition, vision, or touch, where we experience temporal structures through mechanisms such as beat and metre, which are central to how we perceive rhythm and change (Di Stefano & Spence, 2025).

[21] Several scholars have highlighted that olfaction is temporally projected in the past, providing information about earlier events because odour molecules persist in the environment after their source has moved on (Barwich, 2020; Keller, 2017). This makes smell, in daily experience, a "temporal sense" in a way that vision is not being the latter informative of the present moment (or, at least, vision operates on a very different time scale, given the short time it takes for light to reach the eyes). However, the temporal dimension of olfaction arises from interpretive processes rather than from the intrinsic structure of olfactory experience itself. When, for example, a lingering scent suggests that an animal recently passed by, the perceiver is responding to *present* olfactory stimuli—volatile molecules still available in the environment. Similarly, in vision, encountering a fallen tree prompts the observer to infer a prior event, yet the visual perception remains rooted in present stimuli. Consequently, it would be misleading to characterize olfaction as uniquely or essentially temporal. Rather, like other modalities, olfaction delivers present features of the environment, which may then support temporal inferences at a post-perceptual level. The temporal character often ascribed to olfactory experience thus reflects the inferential structure of interpretation, not a fundamental difference in sensory presentation.

[22] Others have suggested a more nuanced understanding of spatiality of olfactory perception. For instance, Aasen (2019) argues that, while it would be false to state that all olfactory experiences are spatial, some clearly are. Aasen suggests that, depending on the context and object of olfactory experience (e.g., odour, smell, or source), perceivers can experience olfactory objects as spatial entities (see also Young et al., 2020).

[23] However, olfaction can guide attention crossmodally. For example, upon detecting the smell of strawberries, one’s visual attention may be drawn toward red objects in the scene.

[24] Note that this difficulty might reflect a (Western) linguistic/cultural bias (e.g., see Majid & Burenhult, 2014).

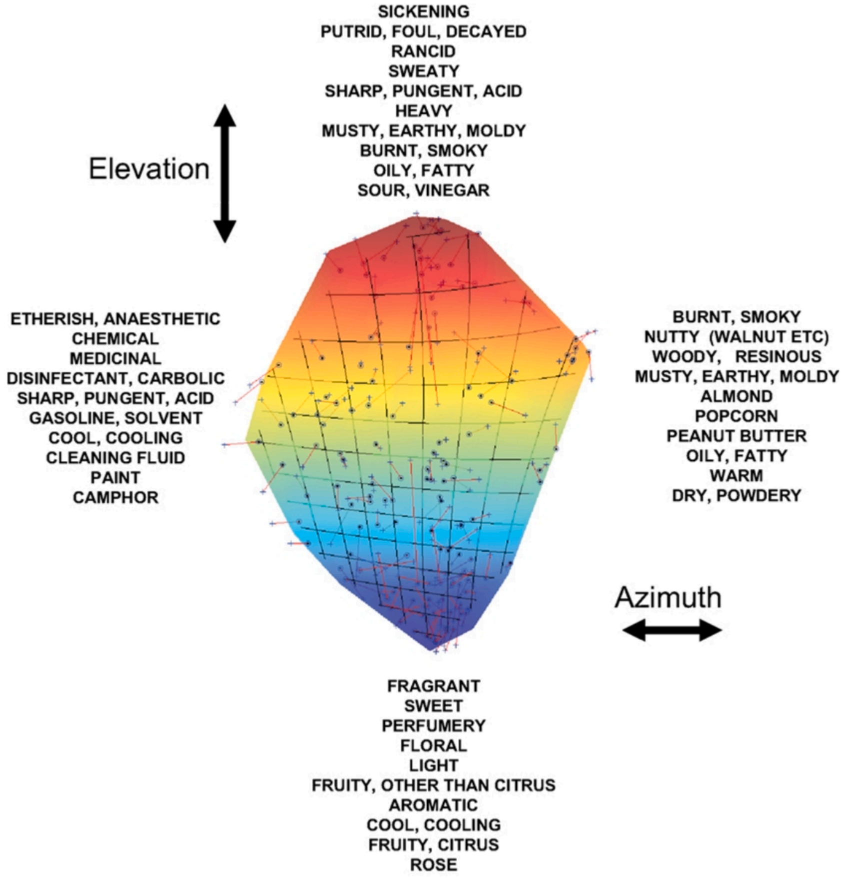

Fig. 2. An example that illustrates the potential complexity inherent in the structure of human olfactory space. From Koulakov et al. (2011).

perceptual switching. In comparison, the dimensions of olfactory and gustatory perception are not as well-understood or agreed upon. While taste is confined to five basic categories (sweet, salty, sour, bitter, and umami), odours are typically classified by qualities such as pleasantness, intensity, or specific scent characteristics (e.g., floral, fruity, spicy). These classifications are often subjective and can vary across individuals and cultures. Due to the lack of intrinsic, intersubjective perceptual dimensions, olfactory and gustatory stimuli offer less potential for the kind of ambiguity that supports multistable perception.

More broadly, we might suggest that the experience of multistability relies on the presence of stable sensory inputs, which, in turn, give rise to stable percepts and perceptual objects. The slower temporal dynamics and the time-varying and evanescent nature of the odours and tastes could undermine the stability required for experiencing distinct alternative percepts. In vision, while there are sources of change—such as colour variations due to changes in ambient lighting—perceptual constancy ensures that objects remain stable and recognizable. For instance, a cube may never project an unchanging image onto the retina, yet we consistently perceive it as a cube. This may relate to the more rigid and well-defined criteria for object identification in vision, which create the conditions for phenomena like illusions and multistability. In contrast, the looser criteria for identifying olfactory objects, and their inherently evanescent nature, may result in more flexible and dynamic percepts, leaving less opportunity for the kind of fixed percepts required to experience bistability. We thus suggest that perceptual constancy plays a pivotal role in limiting multistability in certain sensory modalities (though see Millar, 2019, for an alternative account).

4.4. Cognitive processing of the stimuli

The multidimensionality and complexity of stimuli influence how they are processed in the spatial and chemical senses. Unlike visual stimuli, which are often broken down into distinct features (e.g., colour, shape, texture), chemical stimuli, such as odours and tastes, are processed holistically. When we smell something, we do not typically decompose it into individual components; instead, we perceive it as a unified whole (e.g., the smell of coffee).

The scarcity, if not absence, of empirical evidence demonstrating perceptual phenomena such as amodal completion or filling in within the chemical senses might support the idea that chemical stimuli are perceived holistically (see Young & Nanay, 2022, for a philosophical reflection on amodal completion in olfaction; Spence & Di Stefano, 2024, for a review on amodality more generally). Many examples of amodal completion or filling-in are observed in the visual domain, and possibly also in the auditory and haptic domains. For instance, in vision, the Kanizsa triangle demonstrates how the mind completes the edges of a shape that is partially occluded, while in audition, phenomena like phonemic restoration show how listeners mentally “fill in” missing sounds in a spoken sentence. In the haptic domain, the perception of a continuous surface when touching an object with gaps illustrates similar processes.

The lack of evidence demonstrating similar experiences in the chemical senses suggests that odours and tastes tend to be experienced as complete in themselves. Imagining an odour lacking a component that is then integrated by the perceiver is challenging, as is the experience of filling in for taste. This may be due to the inherently holistic nature of these senses, where stimuli are typically perceived as indivisible wholes rather than as combinations of distinct features.[25] Consequently, this holistic processing leaves little room for multistability—there are no competing interpretations vying for dominance. As a result, chemical senses seem less prone to the Gestalt-like processes that lead to ambiguity and perceptual switching in modalities like vision or audition (though see Millar, 2019).

Scholars have therefore often conceptualized information processing in the olfactory system in a synthetic or configural manner, rather than in an analytical or elemental fashion (Wilson & Stevenson, 2003). In this view, olfactory stimuli are not locally decomposed into smaller elements but are processed as broad, unified sensations. In contrast, visual stimuli can present complexity and ambiguity, allowing the brain to toggle between different interpretations of the sensory input (e.g., seeing a vase or two faces). Odours, however, are processed as single, unified perceptions with specific associations, often source objects (e.g., “this is the smell of roses”). Even when odours are complex, that is, composed of multiple components,[26] the brain synthesizes them into one cohesive experience (e.g., a complex perfume still smells like a unified scent), leaving little opportunity for perceptual switching or multistable perception. This reflects the brain’s inability to individuate the elements of olfactory inputs or, at least, its tendency to process olfactory inputs as inseparable wholes rather than divisible components.[27]

That being said, however, the different ways information is processed in the spatial vs chemical senses must not be rigidly interpreted, and empirical evidence also suggests that individuals can approach tasting experiences either analytically or synthetically.[28] In an analytic mode, people can consciously distinguish the individual components of a complex stimulus. For example, a wine connoisseur might separate out notes of cherry, oak, or vanilla within a single sip, consciously analyzing each flavour note (though perhaps their experience incorporates both perceptually detected components and mentally imagined elements, see Spence, 2023b). In contrast, synthetic processing is a mode where sensory inputs blend into a unified perception. Most individuals without formal training or high levels of experience tend to process flavours synthetically, where complex combinations of taste and smell are perceived as one overall flavour. This approach aligns with how most people encounter flavours in their everyday lives, as the focus is typically on the overall experience rather than on isolated components.[29]

Further insights into the cognitive factors that characterize the processing of chemical stimuli might emerge from the literature on perceptual illusions. Stevenson (2011) provided compelling evidence that olfactory illusions do exist and are comparable to those that occur in the other senses. He suggested, however, that their relative scarcity might be due to a less prominent role of consciousness in olfaction. Stevenson observed that conscious awareness of olfactory stimuli is limited or even absent, which might explain the apparent lack of awareness of olfactory illusions. According to this view, the difficulty of forming a conscious mental representation of an odour, such as recalling the scent of coffee, highlights the uniqueness of olfaction compared to other senses, where recalling visual or auditory images is straightforward (see Zucco, 2003).

Davidson et al. (1999) demonstrated that the perceived aroma/flavour intensity of chewing gum can be substantially modulated by the addition of sucrose, with participants failing to detect menthol retronasally unless sugar was present in the mouth. This observation invites broader reflection on the constructive nature of perception in the chemical senses. In particular, it raises the possibility that phenomena such as odour-induced taste enhancement (see Spence, 2022, for a review) may constitute perceptual illusions, albeit ones that often go unrecognized. We speculate that illusory phenomena may in fact be more pervasive in olfaction and gustation than in vision or audition; however, they are less readily noticed. One contributing factor may be that the recognition of an illusion typically requires the experience of two distinct perceptual interpretations within a short temporal window (see Lycan, 2000). In olfaction and gustation, such rapid alternation may be constrained either by the relatively slow dynamics of attentional shifts or by the rapidity of sensory adaptation and physiological change, which might mask psychological contributions to perceptual variability. Consequently, perceptual reinterpretation in the chemical senses may occur without being consciously attributed to internal perceptual processes, thereby limiting the spontaneous experience of multistability compared to the visual and auditory modalities. Thus, the limited instances of olfactory and gustatory illusions may also imply a lack of perceptual stability rather than multistability. Instead of perceiving

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[25] Wine tasters would object saying that there are both analytic and holistic strategies for tasting wines. While these approaches are possible, they do not reflect the way people normally perceive tastes and odours (Malfeito-Ferreira, 2023).

[26] See Spence & Wang (2018) on the multiple meanings of complexity when referring to the chemical senses.

[27] These remarks would link to reflections in the philosophy of perception concerning the nature of olfactory objects, which go beyond the scope of the present paper. For an overview, see Barwich (2020) and Keller (2017).

[28] Studies have investigated figure-ground segregation ability in animals, demonstrating, for instance, that that mice could be easily trained to detect target odorants embedded in unpredictable and variable mixtures (Rokni et al., 2014).

[29] Lewis and colleagues (2009) conducted a study using Navon letters to assess whether different processing styles influence wine recognition. The results indicated that participants had poorer recognition performance after completing a local Navon task (focusing on smaller letters) compared to a global Navon task (focusing on larger letters). However, this example can be more properly framed in terms of the Gestalt phenomenon of emergence or crossmodal influence of visual perception on taste experiences rather than bistability (see also the recent study by Hagan and colleagues (2025) for a similar protocol involving olfactory stimuli).

alternating facets of a single stimulus, as seen in other sensory examples of multistability, olfaction might involve experiencing distinct, unstable percepts more akin to glimpsing multiple aspects of entirely different sensory "coins."

Linguistic factors may influence taste perception more profoundly than visual or auditory perception (see also Majid & Burenhult, 2014; Majid, 2021). In a study by Robinson (1970), 48 participants first tasted a solution of citric acid, followed by a solution of quinine sulfate and were asked to identify the tastes of the solutions by choosing one or more of the four basic tastes (i.e., sweet, salt, sour, bitter). While only five participants reported no difference between the two solutions, the majority struggled to correctly identify the tastes, even though they could discriminate between them and assign different names. Robinson interpreted this as a naming difficulty, suggesting that participants misused terms like 'sour' and 'bitter.' The explanation proposed is that, since few foods are predominantly bitter, individuals might go through life without clearly identifying this taste. Consequently, someone who has not firmly linked the word 'bitter' to a distinct taste quality may still use it, likely attaching it to an unpleasant taste experience due to its negative connotations (see also Reith & Spence, 2020, for the term "metallic").

Finally, as we have observed earlier, scholars have emphasized the crucial role of attention in olfactory perception, particularly in detecting changes in olfactory stimuli—a phenomenon closely linked to change blindness (e.g., Sela & Sobel, 2010). Research indicates that attention significantly modulates the detection and interpretation of odours, as these stimuli are not continuously processed by the sensory system due to the intermittent nature of respiration and sniffing (see Forster & Spence, 2018, for the impact of visual load on olfactory awareness). This intermittent processing likely necessitates active attentional engagement for individuals to notice changes in odours and render them perceptually salient.

The role of attention in olfactory perception is increasingly recognized as central to understanding the modality's unique phenomenology (Keller, 2011). Unlike vision or audition, olfaction is rarely the focus of endogenous attention (Herz & Engen, 1996), and as a result, odours often remain outside of conscious awareness unless they are particularly intense or behaviourally relevant (Sela & Sobel, 2010). This characteristic may partly explain the scarcity of multistable perceptual experiences in olfaction: without sustained attentional engagement, it may be hard to have the kind of dynamic interpretive shifts seen in other sensory modalities. However, when attention is explicitly directed toward olfactory stimuli—as in trained perfumers or during experimental tasks—there might occur perceptual alternation or reinterpretation over time. Thus, attentional mechanisms may act as a gatekeeper not only for odour awareness but also for the emergence of bistability in olfactory experience [30].

4.5. Informational richness and processing

Compared to other sensory modalities, olfaction in humans exhibits markedly low informational richness and processing capacity (Lycan, 2000, though see McGann, 2017, for a different perspective). Vision dominates in both raw channel capacity and neural resource allocation, with approximately 10^7 bits per second transmitted and 55 % of neocortical area dedicated to visual processing, resulting in 70 % of attentional capture. In stark contrast, olfaction operates with a much lower information bandwidth: a channel capacity of around 10^5 bits per second and an unknown, but presumably minimal, allocation of neocortical resources, resulting in an estimated 5 % of attentional capture. Psychophysically, smell achieves an estimated 1 bit per second of usable information, underscoring its relatively impoverished contribution to perception. Similar values characterize taste, with 1 % of attentional capture and 0.5% of neocortex dedicated to processing (all values retrieved from Gallace et al., 2012). Thus, in the human sensory hierarchy, the chemical senses remain significantly constrained in both information transmission and cognitive processing.

However, while differences in information-processing bandwidth and attentional dynamics across sensory modalities likely contribute to the rarity/absence of bistable or multistable perception in the chemical senses, these factors alone do not fully account for the phenomenon. Olfaction and gustation operate with lower-dimensional stimulus spaces and slower, less voluntarily controlled attentional mechanisms compared to vision and audition. This limits the informational richness and attentional flexibility that enable bistable perception in other modalities. However, more fundamentally, the chemical senses are organized around the detection of global, qualitative fields rather than the structured, spatially arrayed features characteristic of visual and auditory perception. Smells and tastes typically present as undifferentiated or only minimally segmented phenomena, lacking the discrete parts and relationships that are necessary for competing perceptual organizations to emerge. Even if bandwidth and attentional resources were somehow to be equalized, the representational format of chemical perception—dominated by holistic qualities—would still resist the kind of structural ambiguity on which multistability depends. Thus, the absence of multistable perception in olfaction and gustation might not merely reflect a quantitative reduction in sensory input, but a qualitative difference in how perceptual content is encoded and organized.

4.6. Evolutionary reasons

The chemical senses, such as smell and taste, have evolved primarily for survival purposes, such as detecting food, toxins, or pheromones. These senses provide rapid, decisive information crucial for action, which may explain the reduced likelihood of ambiguous interpretations. For instance, an odour signalling danger needs to be quickly recognized and acted upon, leaving little advantage in generating competing interpretations. Consequently, chemosensory stimuli may simply be cognitively less penetrable

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[30] While sensory features awareness and categorical interpretation in vision and hearing can be conceived of as separate steps of stimulus processing, in the chemical senses it may well be that sensory features awareness and categorical interpretation are amalgamated as one integral processing step (see Bachmann & Aru, 2023).

than auditory and visual stimuli (see also Spence et al., 2020; Vetter et al., 2024). The relative impenetrability of gustation might provide an evolutionary benefit given the direct link of these sensations to the ingestion of nutrients or toxins.[31] This connection might also explain their pervasive and impenetrable effect on olfaction in the context of flavour binding, where the presence of these modalities substantially shapes odour experience. The survival function of the chemical senses is reflected in several behavioural effects, including mate selection (Moshkin et al., 2011), social preferences (Li et al., 2007; Todrank et al., 1995), kinship identification (Hold & Schleidt, 1977; Porter et al., 1986), and emotional regulation (Albrecht et al., 2011; Mujica-Parodi et al., 2009). Interestingly, Mollo and colleagues (2022) have recently proposed unifying all chemosensory modalities into a single sense, advancing a synthetic, complex, and interconnected perspective on the gradual processes by which a vast array of chemicals have become crucial signals for communication among and within cells, organs, and organisms across diverse environmental conditions.

Denham et al. (2018) carried out a study to examine whether perceptual switching across vision and audition reflects a common central mechanism or distinct modality-specific processes. They observed significant correlations in switching rates across modalities and consistent individual patterns, indicating some shared underlying dynamics. However, differences emerged at finer levels of analysis, with auditory perception showing stronger temporal dependencies between successive phases and greater variability in phase durations. Notably, switching behaviour did not correlate with central cognitive traits such as creativity or executive function, suggesting that perceptual switching may not be governed by a single, modality-independent control system. Instead, these findings support a model in which similar but separate mechanisms underlie bistability across sensory domains. This distinction is especially relevant for olfaction and gustation, where limited attentional engagement and distinct cortical pathways may constrain the expression of bistable phenomena despite potentially shared architectural principles.

Denham et al.'s (2018) findings may also carry evolutionary implications. Vision and audition are both highly dynamic, distance senses that play a critical role in real-time interaction with the environment, often requiring rapid perceptual updates. The ability to flexibly alternate between competing interpretations may have offered adaptive value in ambiguous or fast-changing sensory contexts. In contrast, olfaction and gustation tend to be slower, contact-based senses, more tightly linked to internal states (e.g., ingestion, threat detection) and less reliant on moment-to-moment perceptual updating. As such, the expression of bistability in chemical senses may be limited not just by cortical architecture or attention, but by evolutionary constraints related to their ecological function.

An alternative perspective on the apparent absence of multistable perceptual experience in olfaction comes from ecological and enactive approaches to perception. From this standpoint, originally articulated by Gibson (1966), sensory information is not inherently ambiguous but is directly specified by the environment and perceived through action-oriented engagement with the world. In this view, the rarity of bistability in the chemical senses may not signal a lack of cognitive dynamics, but rather reflect the olfactory system's distinct mode of processing, namely, its cognitive (relative) impenetrability. In contrast, bistable visual stimuli are typically considered more cognitively penetrable. Relevant here, the empirical literature supports different degrees of cognitive penetrability across the senses, especially in the chemical ones, with stronger empirical evidence for olfaction and weaker for gustation (see Vetter et al., 2024).

5. Conclusions

Returning to the question that inspired this paper, namely, 'Why are olfaction and gustation unique in relation to the phenomenon of bistable perception?', our answer is that the scarcity of clearly documented cases of multistable perception in the chemical senses appears to stem from a confluence of structural, cognitive, and evolutionary constraints that shape how olfactory and gustatory stimuli are processed and experienced (see Table 1). First, these modalities are characterized by limited spatiotemporal resolution, less differentiated perceptual dimensions, and a high degree of perceptual holism—all of which reduce the likelihood of generating competing interpretations of a given sensory input. Second, the inherent time-variability and loose criteria for object identification in the chemical senses prevent observers from forming stable and well-defined percepts, a prerequisite for multistability. Relatedly, the lack of perceptual constancy likely plays a critical role in constraining the emergence of multistability. Additionally, the lower information-processing bandwidth and attentional dynamics in olfaction and gustation likely play a role in preventing from the formation of bistable or multistable perception in these sensory modalities. Finally, the ecological functions of smell and taste—rooted in survival-oriented behaviours such as food selection, threat avoidance, and social signalling—may have favoured perceptual mechanisms that prioritize rapid, stable, and decisive interpretations, rather than ones that allow for ambiguity or alternation.

Unlike vision and audition, where perceptual multistability may reflect a functional flexibility in navigating complex and ambiguous environments, the chemical senses may have evolved according to a different set of priorities. From this perspective, the apparent absence of multistability in olfaction and gustation does not indicate a shortcoming or a gap in sensory processing, but rather reveals a perceptual economy that trades ambiguity for adaptive efficiency. This asymmetry in multistable phenomena across the senses may therefore provide valuable insights into the functional specialization of perceptual systems, and into the broader question of what kinds of cognitive operations are afforded—or constrained—by different sensory modalities. In this light, the absence of bistability in the chemical senses represents a meaningful clue to the evolutionary logic and phenomenological structure of human perception.

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[31] It is worth noting that eating and drinking—activities driven by chemosensory perception—are amongst the most potentially dangerous actions humans routinely engage in, and therefore not activities about which we can afford to be uncertain (Woods, 1991). For this reason, crossmodal effects such as colour influencing taste or sound affecting the perception of carbonation may have a diminished impact during in-mouth evaluation when compared to out-of-mouth assessment (cf. Koza et al., 2005; Zampini & Spence, 2005).

5.1. Open issues and future directions

Several compelling questions arise from the literature and suggest directions for future research. First if bistable perception in vision exemplifies probabilistic processes, does its putative absence in the chemical senses imply that these modalities rely on different perceptual mechanisms? Can computational models, such as predictive coding—which successfully explain multistability in vision and audition (e.g., Weilnhammer et al., 2017)—be adapted to account for the holistic processing in chemical perception? Could these adaptations explain the absence of perceptual switching in olfaction and gustation?

Second, alternative experimental designs or novel stimuli might help reveal context-dependent forms of perceptual switching in smell and taste. The scarcity of bistable stimuli in these senses may reflect a gap in research into their principles of perceptual organization. Future investigations could explore whether these findings highlight fundamental differences in sensory processing or the need for more in-depth research into the organization of chemical senses. Building on evidence of the interaction between imagery and perception in the chemical senses (Spence, 2023b), it would also be fascinating to explore whether vividly imagining a scent (e.g., vanilla) could shift the perceived flavour of an ambiguously-perceived substance (e.g., a vanilla and cinnamon ice cream toward cinnamon) essentially asking whether olfactory imagination can induce adaptation effects (although note that any perceptual alternations so obtained would appear to be voluntarily induced, rather than spontaneous).

Finally, while offering some insights into how to address the questions that inspire our paper, we leave one fundamental, and perhaps unanswerable, question open: What is the impact of the primacy of vision in Western perception science on both the theoretical conceptualization and empirical studies of multistability? In other words, one might ask how perception science, and the concept of multistability, would have evolved had scientists begun by studying olfaction rather than vision (see also Barwich, 2020). While cross-cultural studies offer valuable insights into perception, they are often designed using Western-biased categories, stimuli, and methodologies (see, e.g., McDermott et al., 2016, for a case in music perception). This bias can hinder our ability to obtain reliable and clear results regarding how non-Western (i.e., visuocentric) populations perceive sensory stimuli. In this line, a recent paper by Møller and Köster (2023) argued that olfaction should not be modeled on paradigms developed for vision and audition, but instead understood as an intimate, ecologically embedded sense that conveys unique information inaccessible through the other modalities. They emphasize the need for perceptual research that respects the embodied and contextual nature of smell, rather than abstracting stimuli into isolated laboratory events. From this perspective, the absence of multistability may be seen not as a limitation of olfaction, but as evidence of its resistance to the kind of interpretive ambiguity that gives rise to multistable phenomena in other senses.

CRediT authorship contribution statement

Nicola Di Stefano: Conceptualization, Writing – original draft. **Charles Spence:** Conceptualization, Supervision, Writing – original draft.

Data availability

No data was used for the research described in the article.

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