Language and Cognition (2026), 18, e81, 1–24
doi:10.1017/langcog.2026.10133

ARTICLE

Odor vocabularies diverge in codability but converge in valence and edibility

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(Received 29 May 2026 UTC; Revised 21 October 2026 UTC; Accepted 26 October 2026 UTC)

Abstract

Odors are often difficult to describe, but culturally distinct languages differ in their capacity to express odor experiences. Some languages contain several abstract odor terms expressing odor qualities directly, and thus have odor vocabularies that are high in *abstraction.* This might allow for a high between-speaker consistency – that is, *codability* – in the description of odors. Which aspects of odor descriptions are consistent and which are variable across languages? We hypothesized that cross-linguistic differences in abstraction and codability coexist with cross-cultural similarities on a deeper semantic level, such that odors are primarily differentiated in terms of *valence* (pleasant vs. unpleasant) and *edibility* (edible vs. inedible). No comprehensive cross-linguistic comparison of such odor-semantic organization exists to date. We compare vocabularies for imagined odors of seven languages (Cantonese, English, Polish, Russian, Spanish, Swedish and Turkish). Over 40 speakers of each language ($N = 358$) provided odor descriptors of 121 imagined odors. We analyzed the abstraction, codability, valence and edibility of the resulting vocabularies, comparing their between-odor and between-language variability and their language pair convergence. Odor vocabularies diverge in codability, but converge in valence and edibility. These findings indicate that although languages differ with respect to their encoding of imagined odors, they share the same odor-semantic organization.

Keywords: cross-linguistic comparison; olfaction; olfactory naming; olfactory semantics; sensory language

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1. Background

Olfaction, the sense of smell, is poorly understood in its cognitive and verbal interactions. The impression of odors may evoke vivid memories and strong emotions; a high capacity for emotional learning is critical, as odors serve important functions related to food ingestion, avoidance of hazardous chemicals and in social communication (Stevenson, 2010). However, despite their importance, odors are often extremely difficult to name in the absence of other cues. As much as 90% of people struggle to name some common household odors in free odor identification tests (Hörberg et al., 2024). It has been suggested that the difficulty of naming odor sources, relative to visual objects and sounds, is related to a less extensive cortical pathways linking olfactory perceptual input to language processing areas (Menelaou et al., 2024; Olofsson & Gottfried, 2015). According to this framework, an imprecise mapping of odor-perceptual to lexical-semantic representations makes odor naming and description challenging, and odor perception might instead be guided by predictions based on cues from the environment (e.g., Pierzchajlo et al., 2024). Most languages contain very few basic terms that are used to describe odor qualities (e.g., *stink*). When people do talk about odors, they tend to use words and expressions from other domains (Poulton, 2020), or less specific words for both odor and taste qualities (e.g., *musty* and *pungent*, Floyd et al., 2018). Speakers thus often use either source-based descriptions, which identity odors based on their source (e.g., *citrusy*), abstract descriptions, which either refer to some abstract (e.g., *musty*) or sensory-metaphorical property (e.g., *light*), or evaluative descriptions, which express some subjective evaluation of the odor (e.g., *pleasant*) (Croijmans & Majid, 2016; Hörberg et al., 2022; Majid & Burenhult, 2014; Poulton, 2020). Olfactory descriptions are more often source-based, relative to descriptions of other sensory stimuli (Majid et al., 2018; see also Olofsson & Pierzchajlo, 2021).

Despite the well-documented challenges in olfactory naming and description, some languages have a higher ability to lexically encode odor experiences. In Jahai, a hunter–gatherer language spoken in northern Peninsular Malaysia, odors are described with 12 distinct verbs that express specific odor qualities (e.g., 'to smell roasted', see Burenhult & Majid, 2011; Majid & Burenhult, 2014). Chapálaa, an indigenous language of Ecuador, has a grammaticalized nominal classifier for odors that together with 15 abstract roots make up the Chapálaa odor vocabulary (Floyd et al., 2018). Cantonese, a sister language of Mandarin Chinese spoken in southeastern China, contains around ten abstract terms for odor qualities which primarily are used by older speakers (De Sousa, 2011). Thus, some languages from diverse language families, spoken in both hunter–gatherer communities as well as in industrialized societies, contain well-developed odor vocabularies (see, e.g., Wnuk et al., 2020 and Majid, 2015, 2021 for reviews) with abstract terms designated to express odor impressions.

How do odor vocabularies differ across languages? In the same way as color terms like *brown* and *green* designate specific parts of the color spectrum, abstract odor terms like *floral* and *pungent* denote specific parts of the odor-perceptual space. As such, they provide speakers with tools to lexically encode odor experiences, and thereby facilitate between-speaker consistency in odor naming. How consistently speakers are able to name experiences or phenomena in a particular domain is referred to as *codability*. When generalizing across languages, the sense of smell appears to have lower codability compared to other sensory attributes (Olofsson & Pierzchajlo, 2021). But in a few

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languages with abstract odor terms, codability of olfaction is in some cases higher or on par with the codability of other senses in the language at hand (Majid & Burenhult, 2014; Majid et al., 2018a, 2018b; Majid & Kruspe, 2018). There, thus, seems to be a positive relationship between the extent to which a language contains abstract odor terms to refer to odor experiences, that is, the level of *abstraction* of a language's odor vocabulary, and the consistency of odor description in that language, that is, the language's codability of odors. And whereas some languages have well-developed odor vocabularies with abstract odor terms, others have neither. Odor vocabularies of different languages thus differ with respect to abstraction and codability.

The language of smell appears to be characterized by a poor ability to name specific odor sources, but there is also evidence of cultural variability in abstraction and codability of odor vocabularies. How can these findings be reconciled? A few investigations of the semantic organization of odor vocabularies suggest that a cross-linguistic *divergence* in terms of abstraction and codability might coexist with a *convergence* regarding their primary semantic dimensions. Several studies have found evidence that English odor expressions are primarily differentiated with respect to valence/pleasantness, but also with respect to edibility (Hörberg et al., 2022; e.g., Haddad et al., 2010; Khan et al., 2007; Koulakov et al., 2011; Licon et al., 2018; Winter, 2016; Yeshurun & Sobel, 2010; Zarzo, 2008). For example, Hörberg et al. (2022) used a data-driven approach where odor descriptors were identified automatically in natural texts on the basis of their odor association strength. The semantic organization of those descriptors were then mapped using language modeling. The authors found the identified words to primarily differentiate between pleasant and unpleasant odors, on the one hand, and odors of edibles and inedibles, on the other. Strikingly, a few studies have found that also non-Western languages with abstract odor vocabularies primarily differentiate between odors in terms of valence and edibility in a similar way to English (e.g., Wnuk et al., 2020). For example, Wnuk and Majid (2014) investigated the semantic organization of the odor vocabulary of Maniq, a language spoken by hunter-gatherers in southern Thailand. They found 15 smell descriptors of the language to primarily differentiate between pleasant and unpleasant odors, and secondarily between odors of edibles/safe things, on the one hand, and odors of inedibles/dangerous things, on the other. Similar findings were reported for Jahai (Majid et al., 2018a) and Thai (Wnuk et al., 2020), languages that contain well-developed odor vocabularies. Taken together, these findings suggest that although odor vocabularies diverge across languages in terms of abstraction and codability, they converge in their semantic organization, primarily differentiating between odors in terms of valence, and secondarily, with respect to edibility.

In the present study, we examine this hypothesis with a cross-linguistic approach in which participants describe imagined odors. We investigate the Abstraction, Codability, Valence and Edibility of the vocabularies of imagined odors in eight different languages: English, Spanish, Russian, Cantonese, Polish, Turkish, Hindi and Swedish. This is, to our knowledge, the first study to investigate similarities and differences of odor vocabularies of several languages with respect to how they encode odor experiences as well as how they are semantically organized. Previous studies have investigated odor vocabularies of individual languages (e.g., Beer, 2014; Burenhult & Majid, 2011; Demolin et al., 2016; Floyd et al., 2018; Jędrzejowski & Staniewski, 2021; O'Meara & Majid, 2016; Sharma, 2023; Winter, 2016; Wnuk et al., 2020), or compared vocabularies of two culturally diverse languages

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(e.g., Majid et al., 2018a; Majid & Burenhult, 2014; Majid & Kruspe, 2018) or a few highly related ones (Kobaidze et al., 2021; Lee, 2010). A few cross-linguistic studies of odor language with larger language samples have either investigated 'basic' perceptual verbs more generally (thus including odor verbs, e.g., Norcliffe & Majid, 2024; San Roque et al., 2015; Viberg, 1983) or differences in codability across the senses (Levinson & Majid, 2014; Majid et al., 2018b).

The languages included represent three different language families (Indo-European, Turkic and Sinitic) and thus show some linguistic diversity. Importantly, one of the languages in the sample, Cantonese, was included as it contains dedicated abstract odor words, some of which are less known by younger speakers (De Sousa, 2011). We thus expected the Cantonese odor vocabulary to stand out in Codability and Abstraction.

Using our method to identify odor descriptors in natural texts (Hörberg et al., 2022; Iatropoulos et al., 2018), we first identified odor source names that are evenly dispersed across the olfactory-semantic space. We then conducted an online survey with relatively large samples of participants in each language, where participants provide odor descriptors of imagined odors corresponding to the odor sources. On the level of odor sources as well as the level of individual languages, we then calculate Abstraction and Codability, and obtain estimates of Valence and Edibility, using independent data sources (Díez-Álamo et al., 2018; Guasch et al., 2016; Imbir, 2016; Kapucu et al., 2021; Lynott et al., 2020; Miklashevsky, 2018; Stadthagen-Gonzales et al., 2016; Warriner et al., 2013; Wierzba et al., 2022).

We then evaluate how these languages converge and diverge for these imagined odors, by comparing the between-language variance with the between-odor source variance for Abstraction, Codability, Valence and Edibility. We expect the between-language variance of Codability and Abstraction to be larger than the between-odor source variance, but the between-language variance of Valence and Edibility to be *smaller* than the between-odor source variance. In other words, languages should differ in the extent to which abstract terms are used to describe imagined odors and the degree to which those labels are consistently described. However, they should be similar with respect to whether participants use negatively or positively valenced terms in their descriptions of imagined odors, and with regard to whether they use words associated with edibles or inedibles.

In order to ensure that the odor descriptors of each language are representative of the odor-semantic space (cf. Hörberg et al., 2022), we use a data-driven approach to obtain odor source names. As our method involves the description of imagined, rather than perceived odors, it is dependent on the participants' ability to mentally simulate odor experiences, a cognitive task referred to as *olfactory imageability*. Although some researchers have claimed that people are unable to imagine odors (e.g., Engen, 1982; Herz & Engen, 1996; Royet et al., 2013), plenty of findings show that although odor imageability is more susceptible to individual differences than mental imagery in the primary sensory domains (e.g., Arshamian & Larsson, 2014), the ability to imagine odors seems to be widespread (e.g., Algom & Cain, 1991; Arshamian et al., 2008; Carrasco & Ridout, 1993; Djordjevic et al., 2004; Pierzchajlo et al., 2025; Rinck et al., 2008; Sugiyama et al., 2006). For example, Pierzchajlo et al. (2025) found that similarity ratings of imagined odors (where odor source names, but not odors, were presented) were strongly correlated with similarity ratings of the corresponding, unlabeled odors ($r = .71$), a relationship that was unaffected by age, sex and self-perceived olfactory

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function. These findings indicate that a wide range of people are able to mentally evoke and compare odors when presented with their odor source names. Some studies have also shown that odor imagery activates cortical areas involved in odor perception (Bensafi et al., 2007; Djordjevic et al., 2005; Zelano et al., 2011), paralleling findings in visual in the visual domain (Ganis et al., 2004). Taken together, these findings provide plenty of support for the notion that people can mentally simulate odor experiences when prompted with odor source names, thereby providing justification for our approach.

2. Materials & methods

2.1. Participants

Participants consisted of paid panelists recruited by Qualtrics (Qualtrics, Provo, UT) in exchange for monetary compensation. We aimed for a sample of 60 participants of each language, where five males and five females would be included from each of six age groups (18–24, 25–34, 35–44, 45–54, 55–64 and 64–75 years). English speakers lived in the UK, Spanish speakers lived in Spain, Cantonese speakers lived in Hong Kong, Polish speakers lived in Poland, Turkish speakers in Turkey, Hindi speakers in India and Swedish speakers in Sweden. As Qualtrics were unable to recruit participants from Russia at the time of data collection, native Russian speakers were recruited from Latvia. The initial sample consisted of 51 participants from the UK (26 females, 25 males; mean age: 44.9 years), 60 from Spain (28 females, 29 males, 3 other; mean age: 44 years), 74 participants from Latvia (25 females, 49 males; mean age: 39.1 years), 60 participants from Hong Kong (30 females, 29 males, 1 other; mean age: 43.9 years), 59 participants from Poland (28 females, 30 males, 1 other; mean age: 44.2), 48 participants from Turkey (25 females, 22 males, 1 other; mean age: 46.2 years), 52 participants from India (24 female, 28 male, mean age: 44.8 years) and 52 participants from Sweden (24 female, 28 male; mean age: 44.5 years). With the exception of the Latvian sample, in which females in the oldest and men in the youngest age groups were missing, participants were evenly distributed across age groups. The initial sample thus consisted of a total of 456 participants (209 female, 241 male, 6 other) with a mean age of 43.7 years.

Data from 84 participants was excluded from further analysis, either because of providing blank or erroneous responses (i.e., non-word responses), because of responding in the wrong language (i.e., participants from outside the UK answering in English), or because of a low number of correct descriptions (i.e., only correctly describing less than half of the odor sources). Many of these exclusions consisted of participants from India who completed the survey in English rather than in Hindi. We were therefore forced to exclude Hindi from further analyses. The final sample consisted of 48 participants from the UK (23 female, 25 male; mean age: 45.6 years), 57 from Spain (26 females, 28 males, 3 other; mean age: 45.2 years), 56 participants from Latvia (19 females, 37 males; mean age: 41.8 years), 44 participants from Hong Kong (26 females, 17 males, 1 other; mean age: 44.5 years), 57 participants from Poland (28 females, 29 males; mean age: 44.8 years), 44 participants from Turkey (22 females, 21 males, 1 other; mean age: 46.7 years), and 52 participants from Sweden (24 female, 28 male; mean age: 44.5 years). The final sample thus consisted of a total of 358 participants (168 female, 185 male, 5 other) with a mean age of 45 years.

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2.2. Odor source names

In order to obtain a diverse sample of odor source names, representative of the odor semantic space, words were selected on the basis of the method proposed by Hörberg et al. (2022) and similar to that of Hörberg et al. (2025). In this method, odor words are automatically identified on the basis of the distribution of words in a large data base of natural texts from the web (see Supplementary Materials Section 1 for a description of the text collection used in this study). Words can differ in terms of how strongly they are related to olfaction. A few words are primarily used to express odor qualities (e.g., *smelly*), and therefore strongly associated with olfaction. Other words are also used in many other contexts (e.g., *fresh* can be used to describe pleasant odors, but more often food products, clothing trends, emotional states, etc), and are thus weakly associated with olfaction. We selected 216 source-based odor descriptors on the basis of their olfactory association. To this end, we used a corpus-based measure of olfactory association, the *Olfactory Association Index* (OAI; Iatropoulos et al., 2018) to identify our 216 odor descriptors. We then estimated the distances between these descriptors with a language model that was trained on olfactory contexts from a large text collection of web texts. A language model represents meanings of words as multidimensional vectors called *word embeddings*. Semantic distances between words are then represented as distances in the multidimensional space of the embeddings. We created a map of the odor-semantic space of the selected descriptors on the basis of these distances. This was done by identifying primary clusters of descriptors, using hierarchical clustering, and by establishing the main dimensions along which the descriptors are distributed, applying a Principal Component Analysis (PCA). We finally selected 121 descriptors that are evenly dispersed across this odor-semantic space. This method is described in detail in Supplementary Materials Section 2, and the odor-semantic space, with the selected descriptors highlighted, is illustrated in Supplementary Figure 3. A complete list of descriptors and their semantic properties is found in Supplementary Table 2.

2.3. Survey

We used the Qualtrics survey panel service to construct the online survey in each of the participants' native languages. Participants were asked questions about their age, gender, education, country of residence and mother tongue, as well as a few questions about their sense of smell and taste. Participants were then informed that they would get to describe the smell of 'various objects and phenomena'. They were specifically encouraged to provide abstract and evaluative descriptors to describe odor qualities. More specifically, they were instructed that

> [y]ou may use words that describe qualitative characteristics of the smells such as *musty*, *stale*, *fresh*, *fruity*, *chemical* or *exotic*. You may also use words for individual judgments about the smells regarding, for example, whether they are positive or negative (such as *pleasant* or *disgusting*), familiar or unfamiliar (such as *unmistakable* or *peculiar*), or strong or weak (such as *intense* or *subtle*). You can also use words that describe individual mental or bodily effects or associations that the smells give rise to, such as *appetizing*, *soothing*, or *reminiscent*.

Participants were randomly assigned to one of six groups. Participants of each group were presented with 21–22 odor source names. In order to ensure an even distribution

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of odor sources across groups (e.g., a balanced selection of positive and negative odors), the names were divided in a manner that ensured that each group contained a similar number of names from each of the six odor source categories (see Supplementary Materials Section 2).

The odor sources of each group were presented in six batches of two to four names. These batches were presented in random order. The odor names assigned to each participant group together with their groupings into batches are shown in Supplementary Table 2. Participants could provide as many descriptors as they wanted for each odor source by separating descriptors with semicolons in each input field (e.g., *fruity*; *fresh*; *citrusy*). However, they needed to provide at least four descriptors, as they were required to fill in four fields for each odor source. This survey setup is illustrated in Supplementary Figure 2.

2.4. Data preprocessing

The raw data from each language was manually preprocessed. Non-word responses, responses in another language (e.g., English responses provided by Hindi speakers) and other irrelevant responses (e.g., *blank*, *don't know*, *odorless*) were removed. About 24% of all original responses were excluded (see Supplementary Table 3 for number of exclusions and final inclusions of each language). Remaining responses were spell-checked, lemmatized (i.e., converted into their base forms) and translated into English. This was done by native speakers or near-native speakers of each language.

Descriptors were then manually classified as source-based, abstract or evaluative by the first author of the study, in the same manner as Hörberg et al. (2022). However, we followed Hörberg et al. (2025) in categorizing category names (e.g., *fruity*) as abstract, rather than source-based. An assessment of the interrater agreement, as based on the classification of another person, showed substantial between-classifier agreement (Cohen's $\kappa = 0.66$).

In order to be able to accurately calculate Codability and Abstraction of the level of odor sources (see below), we excluded odor sources that were described with less than ten descriptor types in any of the languages, resulting in the retention of 76 stimulus words.

2.5. Lexical-semantic variables

The vocabularies of each language were compared with respect to the following variables: Codability, Abstraction, Valence and Edibility. Codability and Abstraction were obtained on the level of odor sources, collapsing across individual responses of each Language x Odor Source combination. Valence and Edibility, on the other hand, were obtained on the level of descriptor types of each language.

In previous work, Codability has most often been quantified in terms of the Simpson's Diversity Index of each odor source (e.g., Majid et al., 2018b). It can be seen as a measure of the consistency with which participants describe each imagined odor. Imagined odors that are described with mainly a few unique descriptors (i.e., descriptions are mainly realized as a small set of descriptor types) have a high Simpson's Index, and imagined odors that are described with many different unique descriptors (i.e., descriptions are evenly dispersed across a larger set of descriptor types) have a

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low Simpson's Index. Theoretically, if all participants use the same descriptor to describe an odor, its Simpson's Index would be one, and if all participants use different descriptors Simpson's Index would be 0. As participants were probed for at least four descriptors per label, and therefore by design provide at least four different descriptors, we are unable to obtain the theoretical maximum of one. Simpson's Index is therefore an unsuitable estimate of Codability in the context of our study.

We instead quantified Codability with normalized Shannon entropy. Shannon entropy can here be conceived as a measure that estimates the diversity in the descriptors of an odor source. Normalized Shannon Entropy is highly similar to Simpon's Index, as shown by the measurements' strong negative correlation (see Supplementary Figure 12). Imagined odors that are described with a diverse set of odor descriptors have a high normalized Shannon Entropy, and imagined odors that are described with a similar set of descriptors have low normalized Entropy. Normalized Shannon Entropy *SE* of odor source *i* is

$$SE_i = \frac{-\sum_{j=1}^{n} P(d_j) \log_2 P(d_j)}{\log_2 n}$$

where *d* is the *j*th descriptor token *i*, $P(d_j)$ is the probability that d_j is used to describe *i,* and *n* is the total number of descriptor tokens used for *i*. In Supplementary Materials Section 10, we present the same analyses as below, but with Simpson's Index as a measurement of Codability instead of normalized Shannon Entropy. Both Shannon Entropy and Simpson's Index were calculated on the basis of the distributions of the descriptors in the original languages. A caveat to be considered regarding our Codability estimates is that they are both related to frequency-of-use of the descriptors. Descriptor frequency-of-use is thus a potential confound in our analyses (and in all studies using these estimates). In Supplementary Section 6, we therefore provide additional analyses of the relationships between descriptor frequency-of-use and our Codability estimates, as well as analyses that show that our findings also hold when descriptor frequency-of-use is controlled for.

Abstraction is a measure of the extent to which the imagined odor is described with abstract terms. It is quantified as the proportion of abstract descriptors that are used to describe the odor. Following Hörberg et al. (2025), we use a rather broad definition of abstract terms, which also includes category names (e.g., *fruity*) as well as descriptors referring to the composition of odorants (e.g., *artificial*). This coding decision might have an impact on our findings as some of the descriptors categorized as abstract in English might be less abstract in their original languages. We therefore also performed our analyses using a more conservative definition of Abstraction, only including descriptors that express some odor quality (e.g., *musty* or *pungent*) that often are metaphorically used from another sensory modality (e.g., *light* or *green*). The results of these analyses, presented in Supplementary Materials Section 11, are highly similar to those of our main analyses, and confirm our overall conclusions.

For Valence, we use word valence ratings collected from informants in various online studies. For example, Warriner et al. (2013) collected valence ratings of approximately 14,000 English words. These words were rated on a 1–9 grade Likert scale in terms of their associated happiness, with high ratings corresponding to feelings of being *happy*, *pleased*, *satisfied*, *contented* or *hopeful* and low ratings of

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feelings of being *unhappy*, *annoyed*, *unsatisfied*, *melancholic*, *despaired* or *bored.* To the extent possible, we used valence ratings of words in their original languages. For Spanish, we used the ratings collected by Guasch et al. (2016) and Stadthagen-Gonzales et al. (2016). For Polish, we used ratings from the data sets of Wierzba et al. (2022) and Imbir (2016), and for Turkish we used the ratings of Kapucu et al. (2021). For all other remaining words in all languages, we used ratings of the English translations, taken from the data set collected by Warriner et al. (2013). In total, we were able to assign valence ratings to 80.8% of all odor descriptors in all languages (see Supplementary Table 4 for percentages of both original language ratings and English translation ratings for each language).

Following previous work (e.g., Hörberg et al., 2022), gustatory modality association ratings were used as a proxy for Edibility. Although these two variables are highly related, they are not the same. Gustatory modality association ratings concern the extent to which word meanings are associated with the gustatory modality (i.e., taste). They therefore also apply to words expressing unpalatability, such as *uneatable*, and interpreting them as an index of Edibility must therefore be done with caution. We used gustatory association ratings of words in their original languages to the extent possible. For Spanish, we used ratings from the sensory association ratings collected by Díez-Álamo et al. (2018), and for Russian, we used a few ratings from the data set collected by Miklashevsky (2018). For the remaining descriptors in all languages, we obtained gustatory ratings for the English translations from the sensory modality ratings collected by Lynott et al. (2020). This data set contains ratings of almost 40,000 words that were rated on a 1–5 Likert scale with respect to their association with the olfactory, gustatory, auditory, visual, interoceptive and haptic sensory modalities. We were able to assign gustatory association ratings to 88.5% of all odor descriptors (see Supplementary Table 4 for percentages of both original language ratings and English translation ratings for each language).

Since the ratings of the different data sets used different scales, all ratings were standardized, by subtracting their mean and dividing by two standard deviations (following Gelman 2006, p. 57), before they were pooled. We also evaluated the feasibility of using ratings of English translations by investigating the correlations between original language ratings and their overlapping translation ratings. These analyses, presented in Supplementary Materials Section 5, showed strong positive correlations between translation and original language ratings ($0.7 \leq r \leq 0.9$), attesting to the feasibility of using English translation ratings.

2.6. Statistical analyses

All statistical analyses were conducted in R (R Core Team, 2025). The main hypothesis of the study – that although languages diverge on Abstraction and Codability, they converge on Valence and Edibility – is tested by comparing Abstraction, Codability, Valence and Edibility on their between-language variance with their between-odor variance.

For our main analysis, we fitted a Bayesian multivariate multilevel model predicting Codability, Abstraction, Pleasantness, Edibility from Language and Odor Source (using the `brms` package, see Bürkner, 2017, 2018, 2021). In other words, the model predicts a vector of these dependent variables on the basis of a global intercept,

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a by-language random intercept and a by-odor random intercept.[1] The model thus partitions the data into three sources of variation: the between-language variance, the between-odor variance and the residual variance.

All continuous variables were standardized by subtracting their sample mean and dividing by two standard deviations (following Gelman 2006, p. 57). We used weakly informative priors that are often recommended for data analysis (e.g., Gelman, 2006; Gelman et al., 2008). For the intercepts and the residual errors, we used Student *t* priors centered at 0 with 3 degrees of freedom and a scale of 2.5. For the standard deviation of random effects (i.e., the by-language and by-odor intercepts), we used a Cauchy prior with location 0 and scale 2.5, and for random effect correlations, we employed a LKJ-Correlation prior with the shape parameter set to 1 (Lewandowski et al., 2009). Additional analyses presented in the Supplementary Materials Section 8 showed that our results do not change with either uninformative or stronger priors. The model was fitted using 12 chains with 4,000 warmup-samples and 6,000 post-warmup samples per chain, resulting in 72,000 posterior samples.

For Codability and Abstraction, we expected the between-language variance to be greater than the between-odor variance, whereas for Valence and Edibility, we expected the between-odor variance to be greater than the between-language variance. We tested this by investigating differences in the by-language and by-odor standard deviations for each variable, on the one hand, and by investigating the differences in the by-language and by-odor interclass correlation coefficients (ICCs) for each variable, on the other. The ICC is the proportion of variance explained by a variance component in a multilevel model. It is quantified as the proportion of variance of the component at hand (e.g., by-language variance) and the sum of all variance components (i.e., by-language variance + by-odor variance + error variance).

From the model's posterior distributions, we derived the by-language and by-odor SD and ICC difference distributions and calculated their maximum a posteriori (MAP) estimates, their Highest Density Intervals (HDIs), as well as the Probability of Direction (see below).

In addition to these analyses, we also investigated the correlations between the four variables between all language pairs. The strengths of these correlations reflect the extent to which each of the four variables converge across languages. If languages primarily converge on Valence and Edibility, the across-language correlations should be strongest for these variables. In these analyses, we used the Bayesian correlation coefficient, using the `correlationBF` function, implemented in the package `BayesFactor()` (Morey & Rouder, 2024). R values consist of the MAP estimates of the *r* posterior distributions, and credibility intervals are the lower and upper 95% HDIs.

All statistical inferences are based on the Probability of Direction (p_{dir}), assuming an α of 0.05. P_{dir} is the posterior probability of a parameter (e.g., SD and ICC differences) being zero or taking on values in the opposite direction of the parameter MAP estimate (cf. Makowski et al., 2019), multiplied by 2.

The analysis scripts and the data are available at our OSF repository (see https://osf.io/jstu7/).

[1]That is, {Codability, Abstraction, Valence, Edibility} ~ 1 + (1|Language) + (1|Odor).

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3. Results

3.1. Correlations between lexical-semantic variables

We first investigated the correlations between the lexical-semantic variables. Table 1 shows the pairwise Bayesian correlation coefficients between the variables and their corresponding direction-based *p*-values. As shown in the table, there is a positive correlation between Valence and Edibility, which shows that imagined odors that are described with descriptors more strongly related to Edibility, and thus more likely to refer to edible odor sources, also are more frequently described with positively valenced descriptors. This result, confirming those of previous studies (e.g., Hörberg et al., 2022), is likely to stem from the fact that odors of edibles are more often pleasant than odors of inedibles.

There is also a positive correlation between Abstraction and Valence, and a correlation between Abstraction and Edibility, indicating that pleasant odors of edibles are more frequently described with abstract terms. This is clear from Supplementary Table 11, which lists the top ten English descriptor translations of each odor source and their corresponding across-language estimates of the lexical-semantic variables. Whereas the ten odor sources highest in Abstraction (i.e., the imagined odors being described with the highest proportion of abstract descriptors) all are pleasant odors of edibles (*plum*, *garlic*, *pineapple*, *cherry*, *passionfruit*, *fried chicken*), the ten odor sources lowest in Abstraction include no odors of edibles and only one odor that usually is considered pleasant (*aftershave*).

3.2. Between-language and between-odor variance analyses

We then tested our main hypothesis by analyzing Codability, Abstraction, Valence and Edibility of the odor descriptors in terms of their between-language and between-odor variance. The by odor-source mean scores of these variables are illustrated in Figure 1, and the by language-mean scores are shown in Figure 2. As illustrated in Figure 1, odor sources hardly differ in terms of mean Codability, but display greater differences in terms of mean Abstraction, mean Valence and mean Edibility. As shown in Figure 2, on the other hand, languages differ in Codability, with Cantonese and Swedish showing low mean Codability scores, and English a high score. Languages also differ in Abstraction, with Cantonese, Polish and particularly Turkish showing lower Abstraction scores. Across-language differences in mean Edibility are smaller, with Russian standing out with a higher mean Edibility score. Languages hardly show any differences in terms of mean Valence.

Table 1. Maximum a posteriori (MAP) estimates of Bayesian correlation coefficients of the correlations between the variables, averaged across languages and together with their direction-based *p*-values

	Codability		Abstraction		Valence		Edibility	
Variable	*r*	p_{dir}	*r*	p_{dir}	*r*	p_{dir}	*r*	p_{dir}
Codability	–	–	−0.02	.810	−0.05	0.710	−0.21	.094
Abstraction	−0.06	.776	–	–	0.79	<.001	0.58	<.001
Valence	−0.04	.692	0.79	<.001	–	–	0.60	<.001
Edibility	−0.22	.078	0.56	<.001	0.59	<.001	–	–

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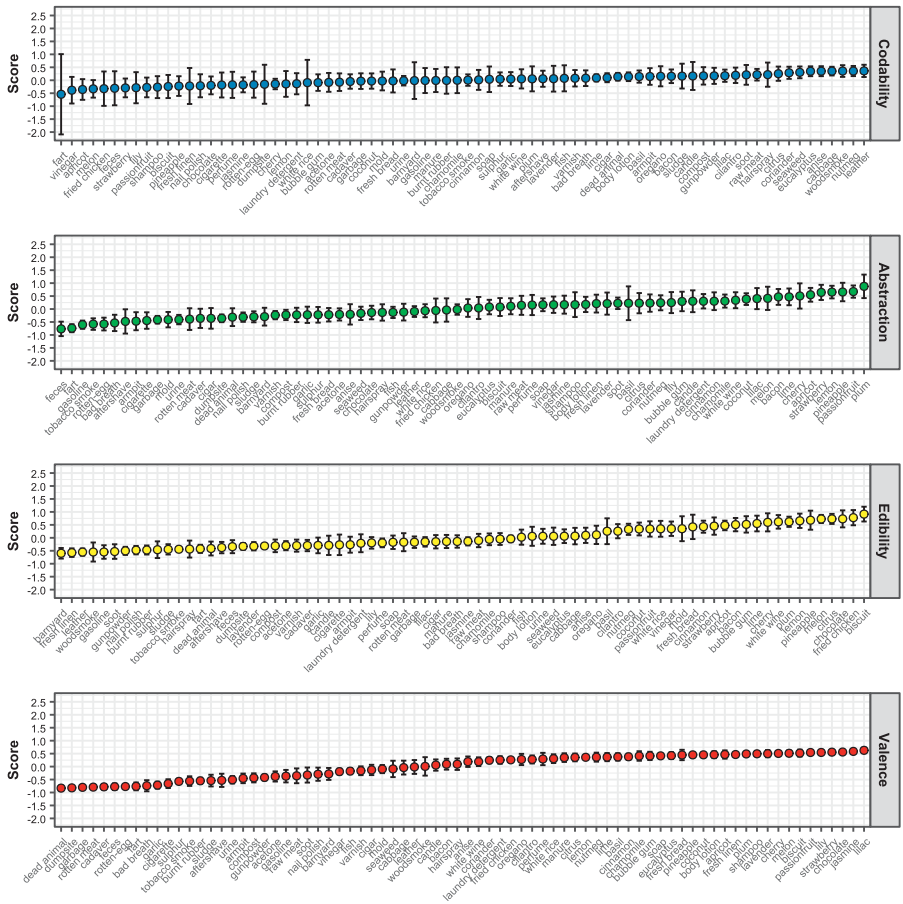

Figure 1. Distribution of observed mean Codability, Abstraction, Valence and Edibility across odor sources. Error bars illustrate 95% confidence intervals.

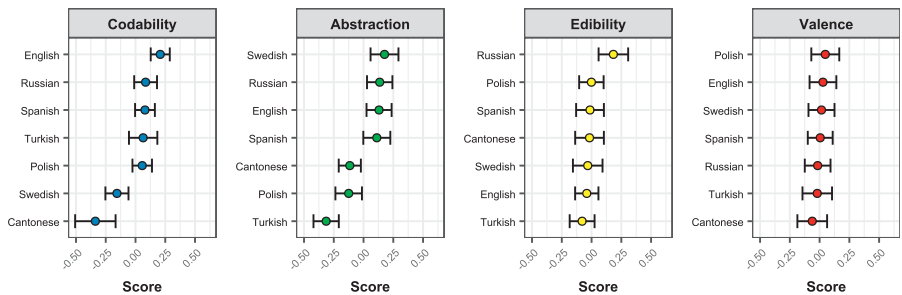

Figure 2. Distribution of observed mean Codability, Abstraction, Valence and Edibility across languages. Error bars illustrate 95% confidence intervals.

In sum, whereas odor labels show little variability in mean Codability but large variability in mean Valence, languages vary greatly in mean Codability but show little variability in mean Valence.

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Table 2. Statistics of the variables' standard deviation (SD) and interclass correlation coefficient (ICC) differences derived from the posterior distributions of the by-odor and by-language SD hyper-parameters in the Bayesian multinomial multilevel model, including maximum a posteriori estimates (MAP), the 95% lower and upper highest density intervals (HDIs), as well as the direction-based p value (p_{dir})

	SD				ICC			
Variable	MAP	Lower HDI	Upper HDI	p_{dir}	MAP	Lower HDI	Upper HDI	p_{dir}
Codability	0.13	−0.02	0.41	.029	0.10	−0.02	0.49	.029
Abstraction	−0.13	−0.26	0.17	.392	−0.30	−0.50	0.30	.392
Valence	−0.42	−0.52	−0.34	<.001	−0.85	−0.90	−0.79	<.001
Edibility	−0.30	−0.40	−0.15	.009	−0.58	−0.71	−0.34	.009

In order to establish differences in between-language and between-odor variances in the lexical-semantic variables, we fitted a Bayesian multivariate multilevel model of these variables as a function of Language and Odor Source which, in essence, partitions these variables into their between-language variance, their between-odor variance and their residual variance. From this model, we then derived the between-language and between-odor SD and ICC *difference* distributions. The results of these analyses are shown in Table 2 and further illustrated in Figure 3.

For Codability, there are positive SD and ICC differences, providing evidence in support of the hypothesis that variance in Codability is higher between languages than between odor sources. For Valence and Edibility, the SD and the ICC differences are instead significantly lower than zero, providing evidence for the hypothesis that their variances are higher between odor sources than between languages. For Abstraction,

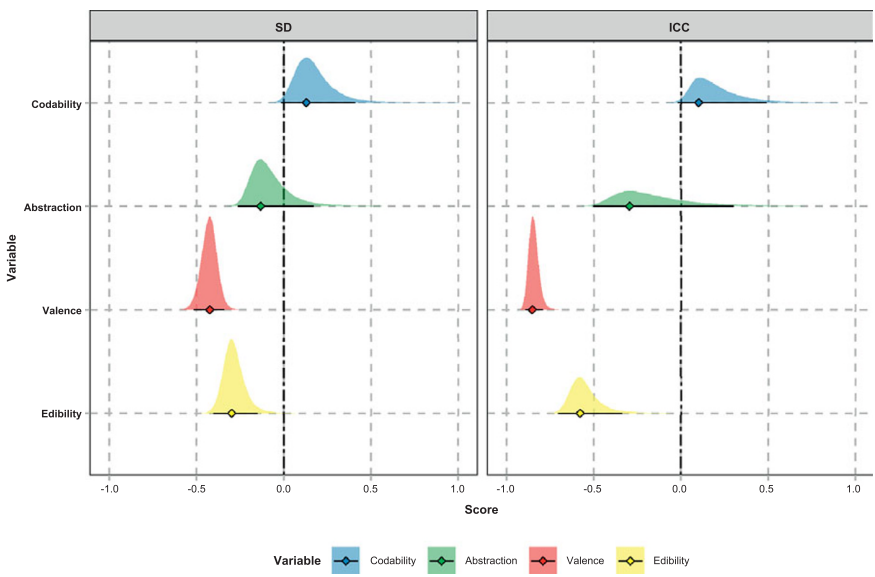

Figure 3. Maximum a posteriori estimates (MAP), credibility intervals (CI) in terms of the 95% lower and upper highest density intervals (HDIs), and posterior distributions of standard deviation (SD) and interclass correlation coefficient (ICC) differences of each of the variables, derived from the by-odor and by-language SD hyperparameters in the Bayesian multinomial multilevel model.

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there are negative SD and ICC differences, but they are not significantly different from zero. Our analysis does therefore not provide support for a difference in between-language and between-odor source variance in Abstraction.

3.3. Between-language correlations of the lexical-semantic variables

We also investigated the between-language correlations of each of the four lexical-semantic variables for all language pairs (e.g., the correlation between by-odor source variables in English and by-odor source variables in Russian, see Supplementary Figure 16 for an illustration). These correlations reflect the degree of convergence of the lexical-semantic variables across languages. If languages primarily converge on Valence and Edibility, their correlations should be strongest across all language pairs. The Bayesian correlation coefficients of these correlations for all language pairs are illustrated in Figure 4 and listed in Supplementary Table 12.



Figure 4. Maximum a posteriori (MAP) estimates of the Bayesian correlation coefficients of the correlations of the variables between all language pairs. Error bars illustrate 95% lower and upper highest density intervals (HDIs).

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The figure also illustrates the credibility intervals of the coefficients. Strikingly, in 18 out of 21 language pairs, the correlations are strongest for Valence and Edibility and weakest for Codability and Abstraction. In three pairs (Swedish–English, Swedish–Polish and Swedish–Spanish), Abstraction correlations are insignificantly higher than Edibility correlations. These findings further confirm the hypothesis that vocabularies of imagined odors of different languages primarily converge on Valence and Edibility, but they diverge in Codability. Imagined odors that are described with negatively valenced descriptors in one language are also described with negatively valenced descriptors in other languages, and imagined odors that are labelled with descriptors related to edibles in one language are also labelled with edibility-related descriptors in other languages. However, the sets of descriptors that are used for a particular odor vary in their size across languages.

4. Discussion

Whereas most languages lack dedicated odor vocabularies, a few languages stand out in their ability to lexically encode odors, containing large inventories of abstract terms expressing odor impressions. Such abstract odor terms provide a means for speakers to consistently name particular odor experiences. Languages thus differ in their odor vocabularies with respect to Abstraction, that is, the abstract odor term frequency, and Codability, that is, across-speaker encoding consistency. At the same time, a few studies indicate that odor vocabularies in radically diverse languages, such as English (e.g., Hörberg et al., 2022) and Maniq (Wnuk & Majid, 2014), are semantically organized in similar ways, primarily differentiating odors in terms of Valence, on the one hand, and with regard to Edibility, Dangerousness or Toxicity (Haddad et al., 2010), on the other.

Here, we conducted the first study to investigate similarities and differences of vocabularies of several languages with respect to how they encode imagined odors and how they are semantically organized. On the level of odor source names, we tested to what extent the odor vocabularies of Cantonese, English, Polish, Russian, Spanish, Swedish and Turkish converge and diverge on Abstraction, Codability, Valence and Edibility. We found the between-language variance in Codability to be larger between languages than between odor sources. Conversely, for Valence and Edibility, the between-odor source variance was larger than the between-language variance, and for Abstraction, there was no significant difference in the between-language and the between-odor source variance. We also found that for most language pairs, the between-language correlations between the four variables were strongest for Valence (mean $r = 0.85$) and Edibility (mean $r = 0.63$), but lowest for Abstraction (mean $r = 0.52$) and Codability (mean $r = 0.07$). In other words, across languages, odor vocabularies were found to most strongly converge on Valence and Edibility, but to diverge on Codability. The variance in Abstraction is similar across languages and odor sources, indicating that vocabularies of imagined odors neither diverge nor converge in terms of Abstraction. However, the Abstraction correlations of all language pairs are significantly higher than zero, providing evidence for some degree of convergence.

These findings confirm our prediction that vocabularies of imagined odors diverge on codability but converge on valence and edibility. Contrary to our prediction, however, we do not find evidence for divergence between odor vocabularies in

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terms of Abstraction. In our main analysis, we found no evidence for a difference in the between-language and between-odor source Abstraction variance, but when a more strict definition of Abstraction was applied, the between-odor source variance in Abstraction was found to be higher than the between-language variance (see Supplementary Materials Section 11). There are also positive Abstraction correlations in all language pairs. These findings suggest that the extent to which a particular imagined odor is described with abstract terms in a particular language is not only dependent on the lexical resources of that language but also on some properties of the odors: the positive correlations suggest that, across languages, some imagined odors are more frequently described with abstract terms than others. Indeed, we found a significant positive correlation between Abstraction and Valence and Abstraction and Edibility, averaged across languages (Table 1). This suggests that, across languages, there is a tendency to more frequently use abstract terms to describe pleasant odors of edibles. Pellegrino et al. (2021) found that odors are described with more abstract descriptors when they are perceived retronasally (i.e., odors enter the nasal cavity via the throat during chewing and swallowing, as part of the multisensory flavor experience) compared to orthonasally (i.e., via sniffing). We speculate that descriptions of pleasant food-related odors may be learned during ingestion and retronasal smelling events, leading to a sustained higher abstraction for food-related odor descriptions, as shown in our present results.

As expected, the odor vocabulary of Cantonese stands out in terms of being higher than the odor vocabularies of the other languages in terms of Codability. However, this does not appear to be due to a higher use of abstract odor words. In Cantonese, 34% of all odor descriptor tokens are abstract (see Supplementary Table 13). This is somewhat lower than the across-language overall percentage of 38%. Indeed, the overall use of dedicated odor terms in Cantonese is quite low. Among the top 40 most frequently used Cantonese odor descriptors, we find only two: 腥 (seng1), which is used 48 times to describe labels of unpleasant odors (e.g., dead fish, sludge, rotten egg), and 餿 (suk1), which is used 11 times to describe labels of acidic, sulfurous and salty odors (e.g., vinegar, garlic, popcorn). It is possible that more dedicated abstract odor words would have been used with an older sample of Cantonese participants (cf. de Sousa, 2011). The mean age of participants that used an abstract odor word (M = 47.58 years) is significantly higher than the mean age of participants that don't (M = 35.45 years; $t(42) = 2.23$, $p < .05$).

More generally, we have argued that the encoding of odor experiences is facilitated by the availability of abstract odor descriptors. This entails that languages in which abstract odor terms frequently are used should also be high in Codability of olfaction. On the level of individual languages, we should thus observe a relationship between Abstraction and Codability such that languages high in Abstraction also are high in Codability. As for Cantonese, this is not a pattern that is found in our data, however. As illustrated in Figure 2, some languages that are high in Codability, are low in Abstraction (e.g., Cantonese and Turkish), and conversely, some languages that are low in Codability are high in Abstraction (e.g., English and Russian). There is also no across-language correlation between Abstraction and Codability (Table 1). These findings thus suggest that it is not the case that Codability of olfaction is higher in languages where odors more frequently are described with abstract terms. This is in line with Majid and Kruspe (2018)'s observation that 'there is no necessary relationship between having "words for things" and psycholinguistic codability' (p. 410). In other words, just because a language has a large set of abstract odor words does not

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necessarily entail that those words are frequently and consistently used by the language users. As an example, Bellamy (2021) investigated the odor vocabulary in Purepecha, an isolate language spoken in central-western Mexico, with an inventory of around 15 abstract odor terms. She was unable to elicit any abstract descriptors in a conventional odor identification task using The Brief Smell Identification Test™, containing odors that are culturally relevant in the US. However, in a follow-up free listing task, almost half of the descriptors produced by her informants were abstract odor terms. The free listing task might allow for 'more opportunity to produce personally or culturally relevant terms' (Bellamy 2021: 150), thereby not being constrained by odors that might be less familiar in the culture under study. Similarly, François (2021) found hardly any uses of abstract odor terms in his corpus-based investigation of odor vocabularies in the languages of northern Vanuatu, although a very rich odor vocabulary with abstract odor terms has been attested in at least one of the languages in his sample. Further investigations showed that odors are talked about in a very limited set of discourse contexts in northern Vanuatu culture, and not usually talked about in everyday life. The use of abstract odor terms might thus in some cultures be limited to specific odors or situations, or, as seems to be the case in Cantonese, may be less frequently used or not used at all by new generations of speakers as a result of a change in cultural norms and practices (but see Strik Lievers, 2021).

It could be argued that our finding that odor vocabularies primarily converge on Valence and Gustation is unsurprising, given that our set of odor source name stimuli was selected to be evenly dispersed across an English olfactory-semantic space that already at the outset is organized along a Valence and Gustation dimension. However, it is important to note that the method by which we map out this space is data-driven and does not rest on any a priori assumptions about the semantic organization of the resulting odor vocabulary. Odor source names are selected only on the basis of their odor association strength, and their semantic organization is derived from their distribution in natural texts. The semantic organization of the identified space is thus not an artifact of our selection method, but rather an inherent property of an odor vocabulary that has been sampled in an unbiased fashion. This semantic organization might very well reflect perceptual and socio-cognitive processes involved in the categorization, differentiation and functional significance of odors (Roberts et al., 2020; Stevenson, 2010), such as determining the quality of food and regulating appetite (e.g., Sorokowska et al., 2022; Van Stokkom et al., 2018), detecting pathogens or other hazards in the environment (e.g., Tybur et al., 2022) or evoking romantic or sexual attraction (e.g., Herz & Inzlicht, 2002; Sorokowska et al., 2018).

The original language sample included Hindi. Unfortunately, we were required to exclude all Hindi data from our analyses due to the low number of participants that performed the survey in Hindi. Out of a total of 52 Indian participants, only 14 completed the survey in Hindi, although they were explicitly instructed to do so.

In this study, we use odor source names to probe for descriptions of imagined, rather than perceived, odors. Our task is thus dependent on the participant's ability to mentally simulate odor experiences. Although our ability for odor imageability is limited relative to other senses (e.g., Engen, 1982; Herz & Engen, 1996; Royet et al., 2013), research indicates that people are quite capable of imagining and evaluating odors when cued by labels (e.g., Algom & Cain, 1991; Arshamian et al., 2008; Carrasco & Ridout, 1993; Djordjevic et al., 2004; Pierzchajlo et al., 2025; Rinck et al., 2008; Sugiyama et al., 2006). In particular, similarity judgments of imagined

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odors are highly correlated with similarity ratings of perceived odors, indicating that odor source names may serve as a valid proxy for the odors themselves (Pierzchajlo et al., 2025; also see Kurfalı et al., 2025). We therefore have good reasons to believe that the descriptors provided by the participants of the present study are similar to those that would have been used for the corresponding real odors, but future studies should assess if the findings presented here also hold for real odor stimuli.

The odor source names used as stimuli for eliciting imagined smells were selected from English on the basis of their olfactory association as quantified in terms of OAI. A potential issue with this approach is that the selected source names might be less strongly related to olfaction in the other languages, and thus less appropriate to use as stimuli for eliciting imagined smells. In order to validate the odor source names, we derived the OAI scores of their translations in each of the included languages, and compared their distributions to that of English OAIs. These analyses, presented in Supplementary Materials Section 2, indicate that the translated odor source names also are appropriate in their respective languages. First, OAI scores of the odor source names in each language are not, apart from those of Spanish, lower than those of the original English source names (see Supplementary Figure 4). The translated names are thus in general equally strongly associated to olfaction as those of English. Second, OAI scores of each language have strong positive correlations to English OAI scores. The translated odor source names are thus differentiated in terms of olfactory association similar to how they are differentiated in English. Whereas words and phrases such as *rotten egg*, *burnt rubber* and *woodsmoke* and their corresponding translations are strongly associated to olfaction, words such as *cookie*, *wood* and *oregano* and their translations are in comparison less strongly associated to olfaction (see Supplementary Figure 5). These results attest to the feasibility of our approach of selecting odor source names from English.

In the present study, we use gustatory modality associations as a proxy for Edibility. However, gustation is highly related to olfaction both perceptually and linguistically. For eating and drinking experiences, retronasal olfaction provides a crucial component (e.g., Pellegrino et al., 2021) and the vocabularies for odors and tastes show great overlap in English and other related languages (e.g., Winter, 2019). Our findings regarding Gustation could thus be driven by differences in olfactory associations: any observed differences between odor sources or languages could stem from differences in odor associations, such as some odor sources being more strongly related to olfaction than others, or some language users being more inclined toward using odor-related descriptors than others. In order to address this potential confound, we conducted additional analyses in which olfactory modality associations were regressed out of gustatory modality associations. The results of these analyses, presented in Supplementary Materials Section 12, did not qualitatively differ from our main findings, thereby showing that our findings regarding gustation also hold when olfactory modality associations are controlled for.

Apart from Codability, the lexical-semantic variables investigated in this study (Valence, Edibility and Abstraction) were to a great extent based on data on the *English translations* of the descriptors, rather than the descriptors in their original languages. For Valence, we used the word valence ratings for some descriptors in Spanish (from Guasch et al., 2016 and Stadthagen-Gonzales et al., 2016), in Polish (from Wierzba et al. 2022 and Imbir, 2016), and in Turkish (from Kapucu et al., 2021). However, most of the valence ratings applied to the English translations of the descriptors, obtained from the data set of Warriner et al. (2013). For Edibility, we

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were able to extract a minority of gustatory ratings for descriptors in Spanish (taken from Díez-Álamo et al., 2018) and Russian (from Miklashevsky, 2018), but most of the gustatory ratings were obtained for English descriptor translations, taken from the data set of Lynott et al. (2020). Abstraction was defined as the percentage of abstract terms corresponding to a particular odor source, and the classification of descriptors into source-based, abstract or evaluative was done by the first author on the basis of the English translations. The validity of our findings thus depends on the extent to which lexical-semantic properties of words are stable across translations. In order to evaluate this across-language stability, we investigated the correlations between Valence and Gustatory modality ratings in their original languages and the ratings of their corresponding English translations. The results of these analyses are presented in Supplementary Materials Section 5. Indeed, we found strong positive correlations between original language ratings and the English translation ratings ($0.7 \leq r \leq 0.9$). These findings are in line with those of Dodds et al. (2015) who found word valence ratings of large sets of word translations (all N:s > 600) of 90 language pairs to be highly correlated (all r:s > 0.7). Taken together, these results provide support of our translational approach, attesting to the stability of lexical-semantic properties across translations. However, future studies would benefit from using lexical-semantic data for the words of the included languages, rather than relying on data of their English translation, in order to provide further support for our findings.

5. Conclusions

In this cross-linguistic study of vocabularies of imagined odors in seven different languages from three language families, we show that although languages differ in their ability to lexically encode odor experiences, they are similar in their odor-semantic organization, differentiating odors in terms of Valence and Edibility. In other words, vocabularies of imagined odors diverge in terms of Codability, but converge with respect to Valence and Edibility. We also find that, contrary to our expectations, vocabularies of imagined odors of different languages overlap in the extent to which particular imagined odors are encoded with abstract odor descriptors. Across languages, pleasant odors of edibles are more frequently encoded with abstract odor terms than unpleasant odors of inedibles. Our findings suggest that although odor vocabularies of different languages differ in their odor encoding strategies, they are semantically organized along similar semantic dimensions, namely Valence and Edibility.

Supplementary material. The supplementary material for this article can be found at http://doi.org/10.1017/langcog.2026.10133.

Data availability statement. The survey data, summary statistics and analysis results, data sets with word valence (Guasch et al., 2016; Kapucu et al., 2021; Imbir, 2016; Stadthagen-Gonzalez et al., 2016; Warriner et al., 2013; Wierzba et al., 2022) and sensory modality association ratings (Díez-Álamo et al., 2018; Miklashevsky, 2018; Lynott et al., 2020), as well as the R code for the statistical analyses are available at this OSF repository: https://osf.io/jstu7/. The original corpus data can be found at https://www.english-corpora.org/now/.

Acknowledgments. The authors thank Billy Gerdfeldter for his help with descriptor classification.

Funding statement. This work is funded by grants from the Swedish Research Council to T.H. (2021-03440), J.K.O. (2020-00266) and M.K. (2024-01506), the Swedish Foundation for Humanities and Social

https://doi.org/10.1017/langcog.2026.10133 Published online by Cambridge University Press

Sciences to T.H. (P25-0745), the Knut and Alice Wallenberg Foundation to J.K.O. (2016:0229) and from The Swedish e-Science Research Center to J.K.O.

Competing interests. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Cite this article: Hörberg, T., de Sousa, H., Kurfalı, M., Szychowska, M., Fredborg, W., Cedres, N., Raj, R., Nilsson, M. E., & Olofsson, J. (2026). Odor vocabularies diverge in codability but converge in valence and edibility, *Language and Cognition*, 18, e81, 1–24. https://doi.org/10.1017/langcog.2026.10133

https://doi.org/10.1017/langcog.2026.10133 Published online by Cambridge University Press