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ARTICLE

Perceptual structure of opposites across sensory modalities

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Abstract
Situated at the junction of Cognitive Semantics and Experimental Phenomenology, this study investigates how participants perceive the structure of 18 perceptual dimensions of opposites across the visual, auditory, tactile, gustatory and olfactory sensory modalities. The structures include three components: two poles (HIGH; LOW) and an intermediate (NEITHER HIGH NOR LOW). Participants were asked to provide examples of contexts for each dimension for which they could experience the five sensory modalities and then describe their experiences of the structures with respect to whether the poles were experienced as a single property (Point), or a range of properties with or without a precise limit (Bounded Range or Unbounded Range respectively). For the intermediate region, they described if they experienced a single property (Point) or many (Range) or none (No Intermediates). The study centres on two main questions. Is the perceptual structure invariant across the sensory modalities? If not, how do the structures differ? The study shows that the overall structure of all dimensions was stable in at least two of the modalities, and many structures were stable across more than two modalities. Stability was particularly pertinent across the visual and tactile modalities, and the gustatory and olfactory modalities.

Keywords: antonym-bipolar dimensions; experimental phenomenology and cognitive semantics; grounded meaning; intermodality and crossmodality; poles and intermediates

1. Introduction

Embodied Cognition and Grounded Cognition have contributed substantially to insights into the fundamental relationship between sensorimotor experience and perception on the one hand, and conceptual processing and representation in language on the other (Barsalou, 2020; Bianchi et al., 2024; Pecher & Zwaan, 2005; Shapiro & Spaulding, 2024; Speed & Majid, 2019; Wilson, 2002). Important advances in research about these relationships have been made in brain research showing that

sensory and motor areas in the brain play significant roles in the neural representation of concepts and in semantic processing more generally (e.g., Barrós-Loscertales et al., 2012; Binder & Desai, 2011; Binder et al., 2016; Fernandino et al., 2016; Patterson et al., 2007; Pulvermüller, 2003; Pulvermüller & Fadiga, 2010; Reggin et al., 2023). The connection has also been investigated in various areas of research on sensorimotor grounding of meanings in language (e.g., Caballero & Paradis, 2020, 2023, 2025; Caballero et al., 2019; Hartman & Paradis, 2023; Majid & Levinson, 2011; Winter, 2019).

In a range of studies of *intermodality*, participants were asked to rate how strongly they experience meanings of individual words related to sight, hearing, touch, taste, smell and motion, and in some studies also proprio- and interoception (e.g., Lynott et al., 2020; Morucci et al., 2019; Muraki et al., 2022; Pexman et al., 2019; Repetto et al., 2022; Speed & Majid, 2017; Vergallito et al., 2020; Villani et al., 2019). These studies have shown that words evoke sensory experiences in more than one modality. *Sweet* is an apt example of intermodal flexibility. Out of context, SWEETNESS may be regarded as primarily associated with taste, but the experience of sweetness extends also to sound (a sweet voice), sight (a sweet smile), smell (a sweet smell), touch (a sweet caress), proprioception (a sweet swing) and interoception (a sweet emotion). Lynott and Connell (2009) asked participants to rate to what extent they experienced adjectives such as *sweet* through sight, hearing, touch, taste and smell on a six-point scale from 'not at all' to 'greatly' – the highest sensory rating was then referred to as the dominant modality for each adjective. This study showed that there is a strong interrelation between sight and touch, and between taste and smell, while the modality of sound was shown to have a more exclusive profile, which means that words that are strongly associated to auditory experiences are less versatile in terms of uses relating to any of the other modalities (Louwerse & Connell, 2011; Lynott & Connell, 2009, 2013; Lynott et al., 2020; Repetto et al., 2022). We return to this issue in the discussion in the light of our results of this study.

In another study of sensory adjectival meanings and their ability to form relations with antonym partners, van de Weijer et al. (2023) paired individual adjectives from Lynott's and Connell's (2009) study in all possible constellations based on whether they could form antonym relations with one another or not. The pairing of antonym partners is dependent on whether they are represented as the poles on one and the same dimension such that, for instance, HIGH and LOW are opposite poles on the dimension of HEIGHT (Paradis & Willners, 2011). Next, based on Lynott's and Connell's (2009) rating data, the dominant modality of each adjective was identified. The results of van de Weijer et al.'s (2023) study showed that, in most cases, the members of the antonymic partners share the same dominant modality, for example, *citrusy* and *sweet* (taste) and *cold* and *tepid* (touch), but not always, for example, *dirty* (sight) and *fresh* (smell), and *fragrant* (smell) and *stale* (taste). They also showed that some modalities combine more easily with one another. For example, particularly frequent were antonym pairs consisting of one member with the dominant modality of smell and the other member with the dominant modality of taste as well as pairs with one member with the dominant modality of sight and the other member with the dominant modality of touch.

In the present study, we take this issue of dimensions of opposites from an intermodal perspective a step further by focusing on the perceptual structure of different dimensions. This is an important aspect for the conceptualisation of meanings both in language and beyond. Also theoretically, the perceptual structuring

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of dimensions is of utmost importance for both Cognitive Semantics and Experimental Phenomenology. The basic assumption of Cognitive Semantics is that cognitive structuring of meanings in general and their expression in language in particular have perceptual underpinnings (e.g., Langacker, 1987; Talmy, 2000; Paradis, 2015a), but research on the perceptual underpinnings has received only limited attention. In contrast, Experimental Phenomenology has perceptual structuring as its focus and, consequently, this aspect has not been neglected (Bianchi & Davies, 2019; Ihde, 2012; Kanizsa, 1979; Kubovy & Pomerantz, 1981). Participants in the present study were asked to define the structure of the three components of perceptual dimensions, that is, the two poles and the intermediate area perceived as neither one pole nor the other, when instantiated in concrete experiential contexts in the visual, auditory, tactile, gustatory and olfactory modalities. To the best of our knowledge, no previous research has been done on the perceptual structuring of dimensions of opposites in order to find out whether (i) the perceptual structure of a dimension is the same across modalities and (ii) if not, how the structure varies across dimensions and modalities.

2. Previous work on sensory modalities and cognitive dimensions

In this section, we first give brief account of previous work on configuration of opposition in language and cognition in the framework of Cognitive Semantics followed by an account of work on perceptual structure in Experimental Phenomenology.

2.1. Sensory content and dimensions between opposing poles

Within the framework of Cognitive Semantics, a fair amount of attention has been given to describing opposing sensory meanings such as WET–DRY, LONG–SHORT, OPEN–CLOSED and their intermediate properties (Jones et al., 2012; Paradis, 2015b; Paradis et al., 2015; Paradis & Willners, 2011; van de Weijer et al., 2014). Paradis and Willners (2011) define binary opposition as a configurational construal where the opposing properties are connected along a conceptual dimension and understood through a cognitive construal of comparison. The perceptual and the cognitive systems form the basis of opposites such as *long–short, heavy–light*, *dead–alive, empty–full* along the dimensions of LENGTH, WEIGHT, EXISTENCE and VOLUME, respectively. Also, some of these dimensions are structured as ranges with a pivotal region representing the area between them. For instance, the dimension of LENGTH with the opposite properties of LONG–SHORT, ranges over conceptualisations such as 'more or less short' or 'more or less long' or 'neither short nor long'. Something may also be FAIRLY LONG, which means that it falls short of being VERY LONG, and the same is true of FAIRLY SHORT. Furthermore, participants locate negated properties such as NOT LONG on the short side of the scale, interpreting it to be co-extensive with FAIRLY SHORT, and vice versa for NOT SHORT. Other dimensions, however, may be divided by a point in an either – or construal, for example, EXISTENCE: DEAD–ALIVE. Somebody is either dead or alive. Yet, other configurations may include both ranges and boundaries, for example, VOLUME: EMPTY–FULL, in which case the range between the poles is limited by the properties of the end points (for details about this see, Paradis, 2001, 2008; Paradis & Willners, 2006).

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2.2. Perceptual structures of experience

In a series of three studies carried out within the framework of Experimental Phenomenology, consistent results were obtained on the perceptual structures of poles and intermediate components of spatial dimensions. In the first study, participants working in interobservation groups produced metric and topological descriptions of opposites for scenes that they looked at directly or retrieved from memory (Bianchi et al., 2011). In the second study, participants classified and rated pictures displaying spatial differences of a property along a dimension (e.g., an empty or a full parking lot, or a flag at the top or the bottom of a mountain) and all experiences in between the extremes (Bianchi et al., 2013). In the third study (Bianchi et al., 2017), participants were asked to mark a set of oppositional dimensions on various images representing spatial scenes. For instance, participants were shown an image of a sandy beach and then marked the part of the image that they perceived as near the water, far away from the water, and neither near nor far away from the water. In this task, their gaze patterns were also recorded with an eye-tracker.

All three studies returned robust results of different types of perceptual structures of opposites. The results of the second and third studies also revealed that there were no significant differences in response times needed to identify the areas corresponding to the intermediates as compared to the poles, and there was very little overlap between the three areas, which indicates that the participants had a precise idea of where the perceptual boundaries between the poles and intermediates were. Finally, the eye-tracking data showed that the areas the participants marked using the mouse were consistent with the areas they scanned with their eyes.

It should be noted that none of the studies of language, conceptualisation, and sensory grounding presented in Section 2.1 included the intermediate component as a separate component. However, it is interesting to note that, apart from technical terminologies, languages typically lack words to express intermediate properties. In English, only a few non-technical words exist such as *lukewarm* or *tepid* (NEITHER HOT NOR COLD). Despite this lack of vocabulary, the experimental results described above suggest that all three components of a dimension hold a spectrum of perceptual experiences.

The three studies resulted in a classification of the poles as a Point (a single experience), a Bounded Range (a limited range of experiences) or an Unbounded Range (an unlimited range of experiences) and of the intermediates as a Point (a single experience), a Bounded Range (a limited range of experiences) or as non-existent (No Intermediate). Using these categories, dimensions may be described as triplets consisting of one Pole, the Intermediate, and the other Pole. Table 1 lists four combinations that in the previous studies were shown to be the most common ones. These four are described and illustrated in more detail below.

Table 1. Perceptual structures of dimensions that have emerged from previous work (Bianchi et al., 2011, 2013, 2017)

Pole a	Intermediate	Pole b
Bounded Range	Bounded Range	Unbounded Range
Point	Bounded Range	Point
Point	No Intermediate	Bounded Range
Bounded Range	Point	Bounded Range

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2.2.1. Bounded Range – Bounded Range – Unbounded Range

The three components refer to properties that participants perceive as phenomenologically modulated ranges, for instance, DISTANCE: NEAR, NEITHER NEAR NOR FAR AWAY, FAR AWAY. There are differences across the three components, both with respect to extension and topology. We know from previous research (Bianchi et al., 2017) that NEAR and NEITHER NEAR NOR FAR AWAY are less extended than FAR AWAY. Moreover, both NEAR and NEITHER NEAR NOR FAR AWAY are spatially bounded ranges, but FAR AWAY is not. For example, the participants from Bianchi et al. (2011) frequently reported that the experience of an object attached to their body is the maximum experience of being NEAR. As this object moves away from them, the moment comes when they first perceive it NEITHER NEAR NOR FAR AWAY and subsequently as FAR AWAY. The participants reported that they could experience various states of being FAR AWAY but not a precise limit. Similar descriptions were given for SMALL–LARGE, and for LOW–HIGH. Participants reported that there is a maximum phenomenological experience of SMALL and LOW, but no corresponding maximum experience of LARGE or HIGH.

2.2.2. Point – Bounded Range – Point

Examples of dimensions that belong to this structure are BEGINNING–END and EMPTY–FULL. Participants in the above studies reported that the poles of these dimensions, for example, the beginning and the end of a running track, an empty and a full bottle, are points, while the intermediates NEITHER BEGINNING NOR END and NEITHER FULL NOR EMPTY are described as ranges of experiences between the poles. However, we acknowledge that in language words such as *full* and *empty* are used to represent ranges (e.g., to describe a glass that is filled but not to the brim or a glass with little left as a request for more). The focus of the three above-mentioned studies was solely on the perceptual experience reported by participants, independently of the language.

2.2.3. Point – No Intermediate – Bounded Range

In contrast to the other perceptual structures listed in Table 1, this dimension has polar components, namely Point and Unbounded Range, but No Intermediates. An example of such a dimension is CLOSED–OPEN. The visual experience of CLOSED in relation to a door, a window, or a drawer is a single experience, while all other cases along the dimension of aperture are perceived as instances of OPEN. There is no NEITHER CLOSED NOR OPEN experience. A door that is ajar is experienced as a little bit OPEN, but not as CLOSED or NEITHER CLOSED NOR OPEN. In practice, however, people may argue whether this door is closed or open.

2.2.4. Bounded Range – Point – Bounded Range

This fourth perceptual structure is represented, for instance, by UPHILL–DOWNHILL or DIVERGENT–CONVERGENT. There are various experiences of these dimensions, but only a horizontal flat surface is perceived as NEITHER UPHILL NOR DOWNHILL. The same applies to two lines that are neither CONVERGENT NOR DIVERGENT, that is two lines that are parallel. Only if they are not, their orientation is perceived as CONVERGENT or DIVERGENT.

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The previous studies of the perceptual structure of dimensions (e.g., Bianchi et al., 2011, 2013, 2017) focused on the visual sensory modality. Participants either looked at images and identified the poles and the intermediates based on what they saw (Bianchi et al., 2013, 2017), or they offered as many visual contexts as they could in which they were able to experience the properties evoked by dimensional triggers and then classified the structure of the poles and the intermediates based on those contexts (Bianchi et al., 2011). No study, however, has focussed on descriptions of perceptual structures in any of the other sensory modalities. This is what we have done in the current study.

3. The present study

The goal of the present study is to describe the perceptual structure of dimensions in the visual, auditory, tactile, gustatory and olfactory sensory modalities. We use the perceptual categories for poles and intermediates shown in Table 1 but extend their scope to all sensory modalities. The investigation is guided by the three main inquiries.

Firstly, can the dimensions be applied in all five modalities? To what extent are participants able to experience dimensions in each of the five modalities? Since each dimension consists of three elements, there are several possible outcomes to this question, ranging from all three may be experienced in another modality, to none of them. If only one pole was perceivable, but not the other one, the dimension was considered not applicable to the sensory modality. This means that we studied the intermodality of dimensions, not words.

Secondly, is the perceptual structure of the dimension stable across the modalities? Are the perceptual structures assigned to the elements of a dimension in one sensory modality the same as those assigned to the dimension in another modality? In other words, how consistent are the perceptual structures across the sensory modalities?

Thirdly, if there is variation in the perceptual structure, what is it like? If the perceptual structures assigned to the elements of a dimension in one modality differ from those assigned to the dimension in another modality, then we will describe the patterns of variation. Since these patterns are not necessarily the same in the poles as in the intermediates, those parts will be described separately.

3.1. Participants

The participants were 30 undergraduate students (13 females and 17 males)[1], all Italian native speakers, recruited from a psychology course at the University of Macerata in Italy (mean age = 21.37 years, sd = 2.23 years). The course was unrelated to the topic of the study. The participants were informed that they would be engaged for around 12 hours in 2-hour weekly sessions, but they did not receive any information about the goal of the study. Their participation was voluntary in exchange for course credits. The study was carried out in accordance with the ethical principles of the Declaration of Helsinki (World Medical Association 2013) and was approved by the Ethical Committee of the University of Macerata (prot. nr. 37413/2023). The students

[1]We had no a priori expectations about the outcomes of the study, and a group of 30 respondents appeared sufficiently large to reveal response patterns, should there be any.

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Table 2. Distribution of participants that perceived the dimension for each of the sense modalities

Dimensions		Sensory modalities				
Italian original	English translation	Visual	Auditory	Tactile	Gustatory	Olfactory
SPIGOLOSO—ARROTONDATO	ANGULAR—ROUNDED	30	30	30	25	25
PULITO—SPORCO	CLEAN—DIRTY	30	30	30	25	30
SECCO—UMIDO	DRY—WET	30	0	30	0	16
PIENO—VUOTO	FULL—EMPTY	30	30	30	28	19
DURO—MORBIDO	HARD—SOFT	30	30	30	23	23
ALTO—BASSO	HIGH—LOW	30	30	30	19	19
CALDO—FREDDO	HOT—COLD	30	30	30	22	23
CHIARO—SCURO	LIGHT—DARK	30	29	0	0	1
LEGGERO—PESANTE	LIGHT—HEAVY	30	30	30	29	30
LUNGO—CORTO	LONG—SHORT	30	30	30	28	28
APERTO—CHIUSO	OPEN—CLOSED	30	30	30	0	20
LENTO—VELOCE	SLOW—FAST	30	30	30	23	24
PICCOLO—GRANDE	SMALL—BIG	30	28	30	0	0
LISCIO—RUVIDO	SMOOTH—ROUGH	30	21	30	0	3
DRITTO—CURVO	STRAIGHT—CURVED	30	29	30	0	0
FORTE—DEBOLE	STRONG—WEAK	30	30	30	30	30
SPESSO—SOTTILE	THICK—THIN	30	24	30	19	18
AMPIO—RISTRETTO	WIDE—NARROW	30	30	30	18	21

signed written consent at the onset, and they were told that they could discontinue their participation at any point in time. None of them chose to do so, however.

3.2. Material

A set of 18 dimensions of opposing properties was used. The dimensions with English translations are listed in Table 2. Most of them had been used in earlier studies (Paradis et al., 2009, 2015; van de Weijer et al., 2012, 2014) and have proven to be appropriate for use in a range of experimental and corpus analytic techniques.

3.3. Procedure

The data were collected in six 2-hour sessions in a classroom at the university. The participants worked in groups of three and continued working in the same groups in all sessions. The groups were seated sufficiently far apart from each other to avoid disturbance or interference. The session time was fixed, but it was at the discretion of the groups to allocate as much or as little time to each of the dimensions as they wanted.

The decision of involving participants in interobservation groups of three people stems from a method developed by experimental phenomenologist Paolo Bozzi (1978/2019; see also Kubovy, 2002) and has been applied in a range of perceptual studies (e.g., Bozzi & Martinuzzi, 1989; Bianchi et al., 2011; Soranzo & Newberry, 2015, 2016). There are two main motivations for the use of the method. First, the focus is on perceptual experiences of external objects or environments shared by the members of the group. This is motivated by the idea that "the coercive phenomenal objectivity of events under observation always makes sense of any invitation to others

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to come and see what we are looking at, with us fully believing that, if they do, they will experience as we do what is there to be seen or heard, possibly even dissenting with our description and helping us with their corrections to notice new aspects" (Bozzi, 2002/2019, p. 16). Second, the method is justified based on experimental evidence that participants involved in complex descriptive tasks in small groups perform better than participants who carry out the task individually. The interaction of group members enhances the quality, precision and consideration of the participants' responses because of reciprocal supervised control with respect to how objects under scrutiny can and should be observed (Bozzi, 2002/2019, p. 18). For these reasons, interobservation was chosen as the method for our study.

In the first session, participants identified which sensory modality each dimension could be experienced in and gave as many examples as they could come up with to support their responses. They were encouraged to think of examples they considered to be typical but also perceptually different from one another. At the end of the first session, each group produced a list of examples of contexts in the five modalities in which they could experience the 18 dimensions. These examples were subsequently collected by the experimenter and then given to all the groups in the second session, to be used in the remainder of the study. This collection is given in Appendix A.

In the remaining five sessions, participants were asked to categorise the perceptual structure of the components of the dimensions as Bounded Range, Unbounded Range or Point for the poles, and as Bounded Range, Point, or No Intermediate for the neither – nor component. The categories were explained with reference to NEAR–FAR AWAY, which is a dimension not used in the present study. The participants were asked to decide if their perceptual experience of NEAR consisted of a single experience (Point) or multiple experiences (Range). If they experienced it as a Range, they categorised it further as a Bounded Range if a precise experience manifesting the property to the maximum extent was perceived, and if not, as an Unbounded Range. The same categories were used to explain the structure of FAR AWAY.

For the intermediate component, participants were asked to say whether they had a single experience of NEITHER NEAR NOR FAR AWAY (Point) or multiple experiences (Range). Intermediate Ranges are necessarily bounded because they are limited by the poles. If they did not perceive any intermediate experience at all, they were instructed to classify them as No Intermediate. Participants were reminded to make their responses based on the contextual experiences that emerged from the examples in the first session and were encouraged to discuss their descriptions in the group before giving their responses. Participants were asked to analyse the perceptual properties in depth, but they were not forced to agree with the other group members in their individual final responses. This is why, after the first session, at the end of the discussions in these interobservation groups, participants individually wrote down their responses (consistent with the method used in Bianchi et al., 2011). An excerpt of the response sheet is shown in Table 3.

3.4. Data analysis

The initial part of the analysis is descriptive with focus on the first research question. We established in which sensory modalities each dimension could be experienced according to the participants, and which the most frequent perceptual structures were to describe the elements of the dimensions within each modality. As the next step, we

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Table 3. Excerpt of the response sheet for the classification of the dimensions' three components

Dimension	Structural elements	Visual	Auditory	Tactile	Gustatory	Olfactory
CLEAN–DIRTY	**Clean** Point, Bounded Range, or Unbounded Range?					
	Dirty Point, Bounded Range, or Unbounded Range?					
	Neither clean nor dirty No Intermediate, Point, or Bounded Range?					

addressed the second research question, determining how often the perceptual structures were the same across the sensory modalities. Given that there were five modalities, 10 modality pairs were needed to get an exhaustive list of the amount of overlap between every combination of two modalities. The differences between these pairs were subsequently tested in a generalized linear mixed effects model for binary data, as described below. Finally, we addressed the third question and looked at the distribution of the perceptual structures across the five modalities. As in the second analysis, we compared the five modalities using a generalized mixed effects regression for binary data. The analyses were done in the R statistical software environment (R-version 4.4.0, R Core Team 2023) with the packages lme4 (Bates et al., 2015), emmeans (Lenth, 2024) and ggplot2 (Wickham, 2016).

4. Results

This section consists of five subsections. The first subsection reports on the distribution of participants' experiences of dimensions in the sensory modalities (Section 4.1). This section is followed by a report on how participants perceive the dimensional structures in the different sensory modalities (Section 4.2). In the next subsection (Section 4.3), the results of the stability of the dimensional structures across the dimensions are described, followed by a section discussing the proportional similarity between pairs of sensory modalities (Section 4.4). Finally, the distribution of the components across the sensory modalities are accounted for (Section 4.5).

4.1. The applicability of the dimensions across the sensory modalities

Table 2 gives an overview of the distribution of the dimensions across the five modalities. As the table shows, participants reported that they were able to perceive all dimensions within at least two sensory modalities. Twelve dimensions applied to all five sensory modalities for most participants (if not all). These results confirm that the set of dimensions was in fact perceptually multimodal.

The participants supported their responses with many examples. A complete list of those is given in Appendix A. The dimension FULL–EMPTY, for instance, was described with reference to vision (e.g., glass, sugar bowl, cinema), audition (e.g., the sound originating from banging a wooden object or knocking a concrete wall or a plasterboard, urban sounds, shouting in a room full of people or empty), touch (e.g., putting one's hands in the pants' pockets, touching a backpack or handbag,

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filling a drawer, perceiving the space left in one's mouth), taste and smell (e.g., richness of tastes and rich fragrances). The dimension SLOW–FAST was described with reference to vision (e.g., seeing the speed perceived of an object, animal, or person), audition (e.g., the speed of a melody, rhythm, speech, a metronome, house alarm), touch (e.g., tapping with hand, finger movement when playing piano, turning a radio knob versus spinning top, pedalling, roller coaster), taste (e.g., the emergence or aftertaste of flavours), and smell (e.g., the speed with which a smell dissolves).

4.2. The perceptual structures of the dimensions across the modalities

In this section, we first give an overview of the most frequent descriptions of the perceptual structures of the dimensions, and then we describe the cases in which a dimension varied in at least one of its three components across two modalities.

The most frequent descriptions of the modal perceptual structures of the poles and the intermediates of the 18 dimensions within each sensory modality are shown in Table 4. Dimensions with the same modal perceptual structure are marked by their background colour, except for five structures which occur only once in the table and have been left uncoloured. The rightmost column of Table 4 shows which sensory modalities share the same modal structure within each dimension.

Table 4 shows that in the auditory, gustatory and olfactory modalities, for instance, the poles of the dimension ANGULAR–ROUNDED were described as Unbounded Range by most of the participants, while the most frequent description of NEITHER ANGULAR NOR ROUNDED was Bounded Range. In the visual and tactile modalities, on the other hand, the intermediate was mostly described as a Point, while one pole in the visual modality, and both poles in the tactile modality were experienced as Bounded Range. Similarly, the poles OPEN and CLOSED were described by most of the participants as Bounded Range for OPEN and Point for CLOSED with No Intermediate in the visual and tactile modalities. In contrast, in the auditory and olfactory modalities, both poles were mostly described as Unbounded Range, and the intermediate as Bounded Range. Finally, FULL and EMPTY were both described by most of the participants as Points in the visual and tactile modalities, while NEITHER FULL NOR EMPTY was described as a Bounded Range. Interestingly, EMPTY was also described as a Point in the other three modalities, and NEITHER FULL NOR EMPTY was described as a Bounded Range in all modalities. FULL, however, was more often described as an Unbounded Range in the gustatory modality and as a Bounded Range in the auditory and olfactory modalities.

As shown in the rightmost column of Table 4, the same modal perceptual structure across at least two sensory modalities was found for 15 out of the 18 dimensions. Four of the dimensions, namely, LONG–SHORT, STRONG–WEAK, THICK–THIN, WIDE–NARROW, had the same modal structure across all five modalities, while two other dimensions, HOT–COLD and LIGHT–HEAVY, were consistent across four modalities. For the other dimensions, where the structure was the same across only two or three modalities, some patterns of modality combinations were invariant, for example, vision and touch. Indeed, 11 out of 18 dimensions were given the same modal perceptual structure in the visual and tactile modalities. In contrast, only 4 out of 18 dimensions were perceived to evoke the same modal perceptual structure in the tactile and gustatory modalities, suggesting that those modalities are relatively heterogeneous. Table 4 also shows that the similarity between modalities appears

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Table 4. Modal perceptual structures of the dimensions within each sensory modality, and groups of sensory modalities that share the same structure

Dimension	Visual (V)	Auditory (A)	Tactile (T)	Gustatory (G)	Olfactory (O)	Groups
ANGULAR–ROUNDED	$UR_{(BR)}$–P–BR	UR–BR–UR	$BR_{(UR)}$–P–BR	UR–BR–UR	UR–BR–UR	AGO
CLEAN–DIRTY	P–NI–UR	UR–NI–BR	P–NI–UR	P–BR–UR	UR–$NI_{(BR)}$–UR	VT
DRY–WET	$BR_{(P)}$–$BR_{(no)}$–BR		$P_{(BR)}$–NI–BR		UR–$P_{(BR)}$–UR	
FULL–EMPTY	$P_{(BR)}$–BR–P	BR–BR–P	P–BR–P	UR–BR–P	BR–BR–P	VT; AO
HARD–SOFT	BR–$BR_{(no)}$–UR	UR–BR–UR	BR–BR–UR	UR–BR–UR	UR– $BR_{(no)}$–UR	VT; AGO
HIGH–LOW	UR–BR–BR	$BR_{(UR)}$–BR–BR	UR–BR–BR	UR–BR–UR	UR–BR–UR	VT; GO
HOT–COLD	$UR_{(BR)}$–BR–$UR_{(BR)}$	UR–BR–UR	BR–BR–BR	UR–BR–UR	UR–BR–UR	VAGO
LIGHT–DARK	BR–BR–BR	UR–BR–UR				
LIGHT–HEAVY	BR–BR–UR	$BR_{(UR)}$–BR–UR	BR–BR–UR	$UR_{(BR)}$–BR–UR	BR–BR–UR	VATO
LONG–SHORT	UR–BR–BR	UR–BR–BR	UR–BR–BR	UR–BR–BR	UR–BR–BR	VATGO
OPEN–CLOSED	BR–NI–P	UR–BR–UR	BR–NI–P		UR–BR–UR	VT; AO
SLOW–FAST	BR–BR–$UR_{(BR)}$	BR–BR–BR	BR–BR–BR	UR–BR–BR	$UR_{(BR)}$–BR–BR	VGO; AT
SMALL–LARGE	BR–BR–UR	BR–BR–UR	BR–BR–UR			VAT
SMOOTH–ROUGH	$BR_{(P)}$–$BR_{(no)}$–UR	UR–BR–UR	$P_{(BR)}$–$BR_{(no)}$–UR			
STRAIGHT–CURVED	P–NI–BR	P–NI–UR	P–NI–UR			AT
STRONG–WEAK	BR–BR–BR	BR–BR–BR	BR–BR–BR	BR–BR–BR	BR–BR–BR	VATGO
THICK–THIN	UR–BR–BR	UR–BR–$BR_{(UR)}$	UR–BR–BR	UR–BR–BR	UR–BR–BR	VATGO
WIDE–NARROW	UR–BR–BR	UR–BR–BR	UR–BR–BR	UR–BR–BR/UR	UR–BR–BR	VATGO

Note: The same perceptual structures are indicated by the same background colours of the cells. Structures which only occur once are left uncoloured. Dimensions are defined by "pole a – neither pole a nor pole b – pole b." UR = Unbounded Range; BR = Bounded Range, P = Point, NI = No Intermediate. Combinations of two categories for the same component of a dimension are reported when the frequency of the second most frequent description (in parentheses) was higher than half of the most frequent one. For NARROW, in the gustatory modality, UR/BR indicates that the two categories were equally frequent.

to be greatest when all three components were either a Bounded or an Unbounded Range. However, invariance also emerged for dimensions that had Point components (e.g., P–NI–UR; BR–NI–P; P–BR–P; and BR–BR–P).

To consider the similarity between the modalities, we next look at the variability of the dimensions in all responses and support the initial qualitative considerations with inferential statistics.

4.3. Stability of the dimensions across the sensory modalities

Table 5 is concerned with the stability of the dimensions across the sensory modalities. It shows how often the participants used the same descriptions of all three components of the dimensions in pairwise combinations of the modalities. Proportions >0.5 (indicated in boldface) generally correspond to cells of the same colours in Table 4. Proportions in italics indicate that a dimension was assessed not to be applicable in the two modalities by more than half of the participants (in this case the similarity lies more on the similar condition of inapplicability of the dimension in the paired modalities, than in the structure of the modality itself). The totals at the bottom of the columns are the proportions of equal responses between two modalities across all 18 dimensions. These totals show that the greatest similarity (i.e., the largest proportion of equal responses) was between the gustatory and olfactory modalities (70%) and between the visual and tactile modalities (57%). The modalities that were least similar were visual and gustatory (22%) and tactile and gustatory (23%).

Table 5. Proportions of cases where the same perceptual structure was used between pairs of modalities

	Modality pairings									
Dimensions	VA	VT	VG	VO	AT	AG	AO	TG	TO	GO
ANGULAR—ROUNDED	0.03	0.50	0.00	0.00	0.13	**0.63**	**0.67**	0.00	0.03	**0.90**
CLEAN—DIRTY	0.13	**0.77**	0.10	0.07	0.17	0.07	0.07	0.03	0.03	0.07
DRY—WET	0.00	0.23	0.00	0.10	0.00	***1.00***	***0.47***	0.00	0.03	0.47
FULL—EMPTY	0.23	**0.90**	0.03	0.07	0.20	0.13	0.27	0.03	0.00	0.13
HARD—SOFT	0.20	0.40	0.17	0.03	0.03	0.73	0.47	0.03	0.03	**0.57**
HIGH—LOW	0.43	**0.63**	0.03	0.00	0.47	0.00	0.00	0.03	0.00	**0.97**
HOT—COLD	**0.60**	0.20	0.47	0.47	0.00	**0.53**	**0.57**	0.00	0.03	**0.83**
LIGHT—DARK	0.00	0.00	0.00	0.03	0.03	0.03	0.03	***1.00***	***0.97***	***0.97***
LIGHT—HEAVY	**0.57**	0.50	0.07	0.40	0.43	**0.30**	**0.57**	**0.33**	**0.53**	0.47
LONG—SHORT	**0.87**	**0.77**	**0.60**	**0.67**	**0.80**	**0.63**	**0.67**	**0.67**	**0.73**	**0.83**
OPEN—CLOSED	0.03	**0.70**	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.33ù
SLOW—FAST	0.43	0.47	0.50	0.50	**0.77**	0.00	0.13	0.13	0.17	**0.63**
SMALL—LARGE	**0.77**	**0.93**	0.00	0.00	**0.80**	0.07	0.07	0.00	0.00	***1.00***
SMOOTH—ROUGH	0.03	**0.73**	0.43	0.43	0.47	**0.77**	**0.77**	0.43	0.43	***0.90***
STRAIGHT—CURVED	0.00	0.33	0.00	0.00	**0.63**	0.03	0.03	0.00	0.00	***1.00***
STRONG—WEAK	**0.87**	**0.80**	**0.87**	**0.87**	**0.80**	**0.90**	**0.93**	**0.80**	**0.77**	**0.93**
THICK—THIN	0.47	**0.70**	0.43	0.43	0.47	**0.77**	**0.77**	0.43	0.43	**0.90**
WIDE—NARROW	0.47	**0.70**	**0.30**	**0.53**	**0.60**	0.47	0.30	0.30	0.50	**0.73**
Total	0.34	**0.57**	0.22	0.26	0.38	0.39	0.38	0.23	0.26	**0.70**

Note: V = visual, A = auditory, T = tactile, G = gustatory, O = olfactory. Proportions >0.5 are in bold. Italics was used for combinations of sensory modalities in which a dimension did not apply, corresponding to the empty cells in Table 4.

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4.4. Comparisons of pairwise structural similarity patterns of sensory modalities

Since our main interest was in the stability of the structure of the dimension, not of its applicability, we excluded 1824 cases without responses in one or both modalities and focused on the remaining 3576 cases where a description in both modalities was available. The similarities between the pairwise comparisons of the modalities were tested with a generalized mixed effects analysis for binary data. The fixed effects consisted of the 10 modality pairs, while the random effects were participant and dimension. The outcome was whether the participant used the same perceptual categories for a dimension in the two modalities or not. The overall effect of modality pairs was significant: the deviance statistics of the model was significantly smaller than that of a model with an intercept only ($\chi^2(9, N = 3576) = 301.23, p < .001$).

The estimated similarities between the modalities with 95% confidence intervals are shown in Figure 1. In this figure, the modality combinations have been ordered from most similar (gustatory–olfactory) to least similar (tactile–gustatory). The figure also shows part of the results of a post-hoc analysis in which the combinations were compared with one another. All pairwise comparisons are given in Appendix B. The *p*-values have been corrected for multiple comparisons (Holm's method). The figure does not suggest clearly separated categories of modality pairs, but two modality pairings shown at the top of the figure were significantly more similar than the remaining eight, namely gustatory and olfactory, and visual and tactile. Additionally, there were four modality pairings, shown at the bottom of

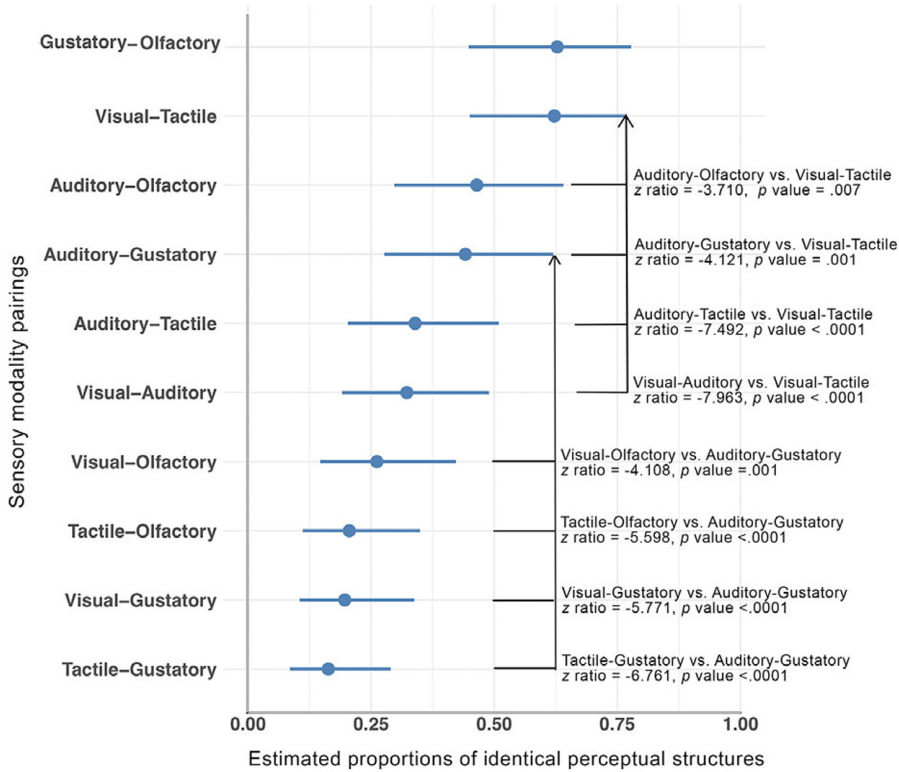

Figure 1. Forest plot showing the estimated proportional similarity between the Modality Pairings that emerged from a mixed effects model, and corresponding significant post-hoc comparisons. Error bars are 95% confidence intervals.

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Figure 1, which were significantly less similar than the remaining ones. Finally, there was a group of four combinations in between these two other groups. Interestingly, this latter group consisted of combinations involving the auditory modality.

4.5. *Patterns of distribution of types of structural components*

Finally, we identified whether there were typical patterns in the perceived structure of the poles and of the intermediates. Figure 2 shows the distributions of the three pole categories (lefthand side) and the three intermediate categories (righthand side) for the five sensory modalities. The left panel of the figure shows that Point pole structures were relatively infrequent overall. They do not take up more than roughly 10% of all responses across the modalities. It also shows that there is a clear pattern for the poles of the dimensions that sets the visual and tactile modalities apart from the remaining three modalities. Within these two modalities, there were more Point responses, more Bounded Range responses, and fewer Unbounded Range responses as compared to the other modalities.

The frequencies of the pole categories across the modalities were compared statistically through generalized mixed effects models for binary data (one for each response category). The random factors in these models were, like in the analysis above, the dimensions and the participants. The fixed effects were the five sensory modalities. The deviance statistics of the three models were significantly smaller than corresponding models with only an intercept. The *p*-values are shown in Table 6.

The statistical analysis of the poles was complemented with post-hoc pairwise comparisons of the modalities. The results (shown in Table 7) partially confirm the visual interpretation of Figure 2.

The difference between the visual and the tactile modalities were not significant for any of the response categories. In contrast, for the other modalities (auditory, gustatory and olfactory), only the Point structure of the poles remained invariant across the three modalities. The frequency of poles described as Bounded Range varied significantly for all three modality pairs (auditory–gustatory; olfactory–auditory and olfactory–

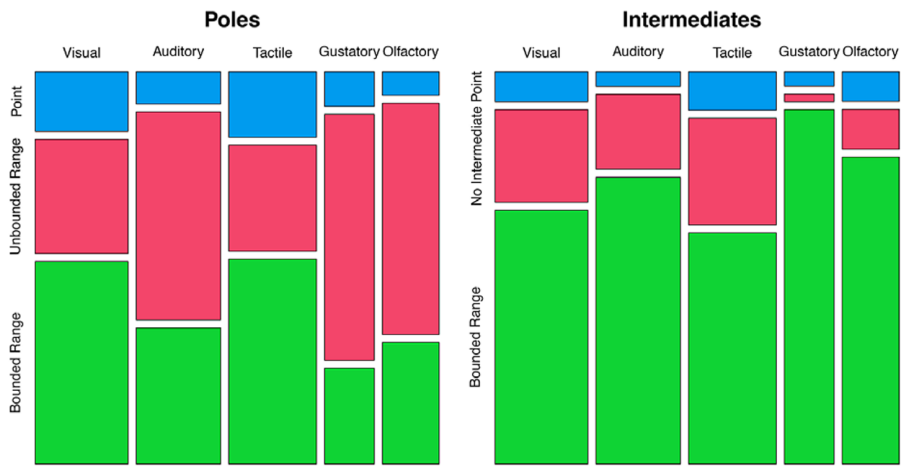

Figure 2. Response category distributions in the poles and the intermediates.

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Table 6. Model comparisons performed on the frequencies of the perceptual categories across the five sense modalities used to describe the poles and the intermediates

Component	Structure	Model fit
Poles	Unbounded Range	$\chi^2(\text{df} = 4, N = 4320) = 486.59, p < .001$
	Bounded Range	$\chi^2(\text{df} = 4, N = 4320) = 336.68, p < .001$
	Point	$\chi^2(\text{df} = 4, N = 4320) = 76.35, p < .001$
Intermediates	Bounded Range	$\chi^2(\text{df} = 4, N = 2160) = 134.97, p < .001$
	Point	$\chi^2(\text{df} = 4, N = 2160) = 20.288, p < .001$
	No Intermediate	$\chi^2(\text{df} = 4, N = 2160) = 125.52, p < .001$

Table 7. Adjusted *p*-values (Holm's method) for post-hoc comparisons concerning the frequency of the modality pairings described with the same category

Modality pairings	Point	Unbounded Range	Bounded Range	Point	No Intermediate	Bounded Range
visual–auditory	0.000	0.000	0.000	0.031	0.233	0.001
visual–tactile	0.637	0.321	0.607	0.799	0.233	0.046
visual–gustatory	0.023	0.000	0.000	0.340	0.000	0.000
visual–olfactory	0.000	0.000	0.000	1.000	0.000	0.000
auditory–tactile	0.000	0.000	0.000	0.001	0.017	0.000
auditory–gustatory	0.371	0.000	0.000	1.000	0.000	0.000
auditory-olfactory	0.635	0.000	0.001	0.058	0.000	0.049
tactile-gustatory	0.010	0.000	0.000	0.047	0.000	0.000
tactile-olfactory	0.000	0.000	0.000	0.831	0.000	0.000
gustatory-olfactory	0.097	0.194	0.001	0.347	0.001	0.000

gustatory). A similar variability was found for the Unbounded Range pole that was invariant only between the olfactory–gustatory modality pair. The intermediates were analysed in the same way as the poles. Like for the poles, also for the intermediates Point responses were relatively infrequent, as shown in Figure 2 (right-panel).

The similarity between the visual and tactile modalities was only confirmed when the intermediates had a Point structure or when there were No Intermediates (not for Bounded Range intermediates). Like for the poles, this again is the modality pair that shows the highest number of invariant structures (two out of three). For the remaining three modalities, we found that the auditory–tactile modality pair was significantly different with respect to all three structures (Point, No Intermediate, and Bounded Range). For the other two modality pairs, there were always two categories that differed and one that remained the same.

Overall, the structure of the intermediates that was most stable was the Point. For seven out of 10 modality pairs the post-hoc tests were not significant, whereas this happened for only two out of the 10 modality pairs for the No Intermediate component, and none of the modality pairs for the Bounded Range component. Something similar holds for the poles, but in that case the stability was confirmed for only four out of the 10 modality pairs.

5. Discussion

As explained in the introduction, this article aimed to contribute to current research on Embodied and Grounded Cognition, more precisely to the sensory grounding of meanings in language (e.g., Caballero & Paradis, 2020, 2023; Connell et al., 2018;

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Hartman & Paradis, 2021, 2023; Lynott & Connell 2009, 2013; Lynott et al., 2020; Majid & Levinson, 2011; Morucci et al., 2019; Repetto et al., 2022; Speed & Majid, 2017, 2019; Vergallito et al., 2020). Our focus has been on the perceptual structure of dimensions connecting opposing poles.

We have focused on the structure of the dimensions in terms of their three components, that is, the two poles and the intermediate region. This is neither a new topic in Cognitive Semantics (Paradis, 2001, 2005, 2008; Paradis & Willners, 2006, 2011; Paradis et al, 2009; van de Weijer et al., 2012, 2014, 2023) nor in Experimental Phenomenology (Bianchi, et al., 2011, 2013, 2017). The novelty of the approach is that we compared the structure of dimensions across five sensory modalities to find out how stable the combination of the structural elements is. To this end, we asked participants if they could perceive a dimension in the visual, auditory, tactile, gustatory, and olfactory modalities without considering one modality as dominant with respect to a specific dimension. Importantly, stability or variation in the perceptual structure of the dimensions is not seen as a case of transfer from a presumed "original" modality to the others but equally natural to all of them, if applicable. Put differently, it is an investigation of transversal stability or instability *across modalities.*

With respect to the first research question concerning whether the dimensions could be perceived in all five modalities, we found that all dimensions were perceivable within at least two sensory modalities. Twelve (out of the 18) dimensions applied to all five sensory modalities for most participants (if not all).

The second research question concerned whether the perceptual structure of the dimensions was stable across the modalities. Two main findings emerged in response to this question. First, a preferential structural association was found between the visual and tactile modalities on the one hand and the gustatory and olfactory modalities on the other. Many dimensions exhibit the same perceptual structure in these two pairs of modalities (see Figure 1 and Table 4). This result concurs with at least two other different lines of research in consistently confirming strong associations between vision and touch, and between taste and smell. Indeed, a strong interrelation between these pairings of modalities also emerged from studies of sensory–motor meanings of words (Louwerse & Connell, 2011; Lynott & Connell, 2009, 2013; Lynott et al., 2020; Repetto et al., 2022).

The same pairings of modalities were observed by van de Weijer et al (2023). They showed that when the antonymic partners differed with respect to the dominant modality. It was usually the case that a meaning with sight as the dominant modality formed pairs with an opposite meaning with touch as dominant modality, or that a meaning with taste as the dominant modality formed pairs with a meaning with smell as the dominant modality. However, the present study has focussed specifically on the structural similarities including the distribution of the poles and the intermediates (Figure 2 and Table 7). We have discovered that the stability of the gustatory and olfactory modality pairing was particularly strong for the poles, where both Point and Unbounded Range were invariant. However, for the intermediates, the poles and the intermediates were more similar in the visual and tactile modalities. Only one difference for intermediates was found for those modalities, namely the Bounded Range experience. All other structural types were invariant for both poles and intermediates.

The other main result in relation to the second research question is that the stability between the auditory modality and the remaining four modalities seems

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debatable. On the one hand, as shown in Figure 1, the four pairings of the auditory modality, that is auditory–olfactory, auditory–gustatory, auditory–tactile, auditory–visual, were shown to be less stable than the gustatory–olfactory and visual–tactile pairings, but the auditory–olfactory and auditory–gustatory pairings were significantly more stable than the visual–olfactory, tactile–olfactory, visual–gustatory, and tactile–gustatory pairings. In view of this, the stability of the dimensions is not as low as expected based on previous results about word meanings. On the other hand, when analysing the stability of specific structures of poles or intermediates (Table 7), it turned out that the stability of the structures between the auditory modality and the other modalities was limited to specific structural components, namely two structural components for the olfactory–auditory pairs, that is, in both cases, Point pole and Point intermediate and one for the visual–auditory pair, that is No Intermediate, while no structural component was shown to be invariant for the auditory–tactile pair.

These findings seem to be more in line with findings in previous work about the sensory meanings of individual words in language, showing that words with the dominant modality of audition were less versatile in terms of uses in other modalities (Louwerse & Connell, 2011; Lynott & Connell, 2009, 2013; Lynott et al., 2020; Repetto et al., 2022) and less prone to form antonymic relations with other sensory modalities (van de Weijer et al., 2023). In contrast, Hartman's and Paradis' (2023) study, which is based on participants' written descriptions of their experiences of acousmatic sounds, showed that there was a prominent association of meanings related to touch in the descriptions of acoustic stimuli. In our study, the structure of poles and intermediates indicates that there is a low degree of stability between the auditory and tactile modalities (see Figure 2 and Table 7). This said, it is important to keep in mind that sensory meanings of words are not the same as the perceptual structures of sensory modalities, and therefore these findings are not necessarily in conflict with one another.

The third research question concerned the most typical patterns of instability of the poles and of the intermediates. The overall structure of the dimensions including all three components, that is the two poles and the intermediate region was stable across for at least two modalities for most of the dimensions and for many dimensions also beyond two modalities (see Table 5). However, also a sizable proportion of cases showed variation in the perceptual structure, either in the poles or in the intermediates (Table 7). As the left panel of Figure 2 shows, the poles were more frequently a Point or a Bounded Range in the visual and tactile modalities, while in the other modalities, the Unbounded Range structure for the poles was more common. This suggests that Unbounded Range poles in the auditory, olfactory and gustatory modalities tend to be perceived as Points or Bounded Ranges in the visual and tactile modalities. In case of the intermediates, the most interesting pattern is the discrepancy between the experiences of No Intermediates in the visual, auditory and tactile modality on the one hand and the olfactory and gustatory modalities on the other. In other words, in the visual, auditory and tactile modalities, the poles often extend over the main part of dimension due to the fact that many participants report that they do not experience an intermediate component, while this is not the case for the gustatory and olfactory modalities where the passage from one pole to the other often consists of experiences identified as NEITHER –NOR.

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Finally, a thought-provoking result is that the similarities are not necessarily consistent between poles and intermediates. For instance, the stability of the perceptual structures of dimensions between the visual and tactile modalities hold for both the poles and the intermediates, whereas the stability of the perceptual structure for the gustatory and olfactory modalities concerns the poles more than the intermediates. New empirical research with specific focus on these modality pairings might clarify when this happens and why.

As always, there are also limitations for generalisations of the results that must be kept in mind. First, it cannot be a priori excluded that these results might be idiosyncratic for the set of dimensions studied. However, the set was chosen because these dimensions have previously been shown to be associated with strongly opposing poles and with possible intermediate parts. Future studies will show if the findings can be generalised to other sets of dimensions or not. Secondly, the study was carried out in Italian and therefore there is a potential risk that these findings hold in the Italian context. It would be interesting to investigate the same dimensions in other languages and cultures. For instance, in the case of the dimension liscio–ruvido (smooth–rough), no participant indicated that this dimension could be perceived through taste (see Table 3). In Italian, it is indeed not common to find these adjectives used to describe taste, except perhaps in specialised texts such as wine tasting, while in English *smooth taste* is applicable in a wider range of contexts than *gusto liscio*.[2] However, as argued above, the focus of this study is on the perceptual structures, and for the majority of the dimensions considered in our study, the poles are very general and range over many contexts.

The main purpose of the study was to explore the information that might emerge from this approach and to encourage more experimental work and theoretical considerations related to the topic of opposites, looking more broadly at their stability and instability across the senses.

Data availability statement. Link to the dataset: https://osf.io/vqd2e/.

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Appendix A. List of experiential contexts, provided by participants in the first session, in which the properties listed in the first column are perceivable within each sense modality (visual, auditory, tactile, gustatory and olfactory)

Opposites	Visual	Auditory	Tactile	Gustatory	Olfactory
OPEN—CLOSED	Window, door, zip, drawer, cork bottle stopper, buttonhole button, press stud	Voice, laughter, vocals' sound (open/closed), timbre of instrument, sound of a hit at an object (gong vs can), clear (unblocked) sound vs muffled sound	Box, screw cap of jar/bottle, mouth, book, door, drawer, shoe sole (loose vs. re–fastened), buttonhole button, press stud, laptop screen		Fresh air smell vs stuffy indoor smell
FULL—EMPTY	Glass, bottle, sugar bowl, bag, cinema	Sound originating from banging an object (wooden object, concrete wall vs plasterboard), urban sounds in the city, shouting in the room (full of people vs. empty)	Pocket, backpack, handbag, case, drawer, mouth, hands	Taste food/course rich vs tasteless, drink vs water	Smell rich of many fragrances vs. unscented air
HARD—SOFT	Any object or surface, cushion, chocolate (melted vs. solid), biscuit	Tone of voice, sound of letters, sound of instruments, musical style (hard rock vs soft rock; heavy metal vs ballads), falling object	Seat, backrest, cushion, cheese, bread, meat, any object (iron, wood, foam), leather and sole of shoes,	Taste (grappa, coffee, chocolate, beer, wine)	Odours and scents (alcohol/bleach as examples of hard smells; flowers, wood as examples of soft smells)
HIGH—LOW	Height of person, building (seen from outside), room (seen from inside), tree, shelves, ladder, plane flying above our heads, heels/ stilts	Sound volume, voice tonality, note tonality	Touch height of door, pole, column; bookcase shelves, supermarket shelves, step	Taste of notes/ aromas wine, amount of alcohol	Notes of perfume
LONG—SHORT	Bridge, avenue in city of path in park, row of people/cars, rope, branch	Duration of a sound, note, howl, concert, speech/talk	Handrail, broomstick, rod, rope, table	Persistence of taste (cigarette, wine, coffee, chili pepper)	Persistence of smells, that is persistent vs punctual smells (sea, gas, wisteria–lined avenue, forest, mint, rain,

(*Continued*)

(*Continued*)

Opposites	Visual	Auditory	Tactile	Gustatory	Olfactory
					incense vs a small cyclamen, a single rose)
LIGHT—DARK	Color, ambient light, sky	Voice timbre (shrill vs bass voice) and instruments timbre (piccolo violin vs bass, bass horn)			
SMALL—LARGE	Any object (crumb, sand, pebble vs boulder, mountain) or space (garden, park), needle eye	Soft chime vs. loud boom; collision bang, thunder, feeble	Any objects (rock, box, chair, glass, table, sphere)		
SLOW—FAST	Movement of any object (car, motorcycle) animal (sloth, snail, hare) or person (walking, running)	Melody, rhythm, speech, ticking, metronome, house alarm, sewing machine	Tapping with hand, finger movement when playing piano, turning radio knob vs. spinning top, pedalling, pushing, roller coaster (going up vs going down), blinking, massage	Aftertaste versus immediate taste (spicy)	Smell that passes through and dissolves immediately vs slowly
STRONG—WEAK	Light, color (bright/dull), plant stem, human build (muscle mass), window glass, paper (tissue vs cardboard)	Sound, voice (faint vs shrieking), noise, thunder, whistling, sound of falling object, rain splatter	Touch vs punch/slap; branch breaking; object breaking – cotton thread, paper vs metal, fabric (gauze vs tough cotton)	Taste (spicy, bitter, white meat vs game, alcohol)	Pleasant or unpleasant smell (perfume, food, flower, animal odour, stink) barely perceivable vs. intense
HOT—COLD	Colors, light	Voice timbre/quality, instrument timbre, sounds, chords	Any object in contact with the skin (radiator on–off) but also air (phone vs icy mountain), water felt with hand/foot/body, in the mouth (e.g. soup)	Tastes (chocolate vs. mint/citrus)	Scented tones/notes
SMOOTH—ROUGH	Any surface (paper vs sandpaper; fabrics, wall, door, sponge, tabletop, floor)	Sound (backwash of waves of a calm sea, musical scale vs strident/croaking sound), voice, continuous sound of wind	Anything touchable (table surface, facial skin, fabric; Modica chocolate vs ordinary chocolate), rock, leather		
THIN—THICK				Taste of wine	

(*Continued*)

(*Continued*)

Opposites	Visual	Auditory	Tactile	Gustatory	Olfactory
	Sheet, slab, rope vs wire, wall, blanket, shelf, lens of spectacles, slice	Voice, sound, laughter, bells chime, drop, squeak, plucked sound, guitar stings	Sheet, table, shelf, book, glass, rope, chocolate layer, steak		Smell (with few notes vs many notes, complex)
LIGHT–HEAVY	Anything (clouds, smoke, foam, marble, boulder, bridge, plastic bag)	Instrument timbre, noises, sound of plunge in water, voice, tapping on the roof (rain vs hail)	Anything (dumbbell, suitcase, fabric, clothing)	Taste intensity; taste quality	Intensity of a nice smell or bad smell; smell quality (e.g. fresh laundry vs cigar)
WIDE–NARROW	Environment (square, street, lounge), clothes, vacuum packed items	Orchestra sound, gong, opera song, echo, roar, storm sound vs trill, chime, cry of cricket, coffee spoon sound in cup)	Ring, watch, dress, shoes, elevator, tunnel/corridor, hole in a fabric, crack in the wall	Flavours of hot chocolate, enveloping wine versus vinegar, lemon juice	Extensive/diffused vs localized and circumscribed scent; scent smelled from different distances and extended vs pungent and circumscribed
DRY–WET	Soil, sand, road, fabric, crunchy cookies versus creamy desserts, babà; bread (dry vs soggy)		Air, cookie (dry or soaked), skin, hair, ground, wood, leaves, laundry, sponge		air/wind, forest smell
ANGULAR–ROUNDED	Any object/shape (face, table, corner, building, architectural style/ design)	Voice (edgy vs deep), sound (strident vs hugging), timbre (electric guitar vs piano), music genre	Any object or space, edges of objects	Sour/acrid taste versus sweet, smoky, peaty (whiskey, cigars)	Acrid smells (bleach, pure alcohol, burnt) versus smoky, vanilla, peat
STRAIGHT–CURVED	Road, line, posture	Constant sound (constant whistle, linear crescendo or diminuendo) vs. inversions of crescendi/diminuendi, Yodel, ambulance siren.	Any object or furniture contour, rod vs. boomerang/ curved branch, straight handrail vs. spiral staircase		
DIRTY–CLEAN	Glass/window, mirror, water, fabric/ tablecloth, plate, floor	Sound recording or interception (welldefined vs disturbing/rustling/ with interference)	Smooth versus sticky, greasy, dusty	Simple tastes, well–identified tastes vs.dissonant mixture, mess	Clear smell vs.mismatched odors; air smelling good vs. stench/mold

Appendix B. Post-hoc comparisons between modality pairs (complement to Figure 1)

	EST	SE	df	*t*	*p*
visual–olfactory – visual–auditory	−0.294	0.180	Inf	−1.637	0.814
visual–olfactory – visual–gustatory	0.372	0.203	Inf	1.834	0.600
visual–olfactory – visual–tactile	−1.535	0.178	Inf	−8.632	0.000
visual–olfactory – auditory–olfactory	−0.895	0.191	Inf	−4.680	0.000
visual–olfactory – auditory–gustatory	−0.801	0.195	Inf	−4.108	0.001
visual–olfactory – auditory–tactile	−0.371	0.180	Inf	−2.063	0.392
visual–olfactory – gustatory–olfactory	−1.560	0.202	Inf	−7.728	0.000
visual–olfactory – tactile–olfactory	0.314	0.198	Inf	1.586	0.814
visual–olfactory – tactile–gustatory	0.599	0.206	Inf	2.904	0.048
visual–auditory – visual–gustatory	0.666	0.190	Inf	3.514	0.008
visual–auditory – visual–tactile	−1.241	0.156	Inf	−7.963	0.000
visual–auditory – auditory–olfactory	−0.600	0.175	Inf	−3.425	0.010
visual–auditory – auditory–gustatory	−0.507	0.180	Inf	−2.813	0.059
visual–auditory – auditory–tactile	−0.076	0.158	Inf	−0.482	1.000
visual–auditory – gustatory–olfactory	−1.266	0.187	Inf	−6.760	0.000
visual–auditory – tactile–olfactory	0.609	0.184	Inf	3.300	0.015
visual–auditory – tactile–gustatory	0.893	0.193	Inf	4.615	0.000
visual–gustatory – visual–tactile	−1.907	0.190	Inf	−10.058	0.000
visual–gustatory – auditory–olfactory	−1.267	0.200	Inf	−6.322	0.000
visual–gustatory – auditory–gustatory	−1.173	0.203	Inf	−5.771	0.000
visual–gustatory – auditory–tactile	−0.742	0.189	Inf	−3.920	0.002
visual–gustatory – gustatory–olfactory	−1.932	0.210	Inf	−9.188	0.000
visual–gustatory – tactile–olfactory	−0.058	0.206	Inf	−0.279	1.0000
visual–gustatory – tactile–gustatory	0.227	0.213	Inf	1.067	1.0000
visual–tactile – auditory–olfactory	0.640	0.173	Inf	3.710	0.004
visual–tactile – auditory–gustatory	0.734	0.178	Inf	4.121	0.001
visual–tactile – auditory–tactile	1.164	0.155	Inf	7.492	0.000
visual–tactile – gustatory–olfactory	−0.025	0.184	Inf	−0.136	1.000
visual–tactile – tactile–olfactory	1.849	0.183	Inf	10.097	0.000
visual–tactile – tactile–gustatory	2.134	0.194	Inf	11.005	0.000
auditory–olfactory – auditory–gustatory	0.094	0.191	Inf	0.492	1.000
auditory–olfactory – auditory–tactile	0.524	0.175	Inf	2.994	0.039
auditory–olfactory – gustatory–olfactory	−0.665	0.197	Inf	−3.380	0.012
auditory–olfactory – tactile–olfactory	1.209	0.196	Inf	6.180	0.000
auditory–olfactory – tactile–gustatory	1.493	0.204	Inf	7.312	0.000
auditory–gustatory – auditory–tactile	0.430	0.180	Inf	2.393	0.184
auditory–gustatory – gustatory–olfactory	−0.759	0.200	Inf	−3.795	0.003
auditory–gustatory – tactile–olfactory	1.115	0.199	Inf	5.598	0.000
auditory–gustatory – tactile–gustatory	1.340	0.207	Inf	6.760	0.000
auditory–tactile – gustatory–olfactory	−1.190	0.187	Inf	−6.362	0.000
auditory–tactile – tactile–olfactory	0.685	0.184	Inf	3.717	0.004
auditory–tactile – tactile–gustatory	0.969	0.193	Inf	5.013	0.000
gustatory–olfactory – tactile–olfactory	1.874	0.206	Inf	9.088	0.000
gustatory–olfactory – tactile–gustatory	2.159	0.214	Inf	10.080	0.000
tactile–olfactory – tactile–gustatory	0.284	0.209	Inf	1.359	1.000

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