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ARTICLE

Sensory modality profiles of antonyms

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Abstract
Adjectives that are used to describe sensory experiences are often used to express more than one modality. The adjective *sweet*, for instance, may primarily be associated with taste (i.e., taste is the dominant modality of sweet), but it can also be used for smell, sound or sight, and possibly even for touch. It has also been shown that some sensory modalities combine more easily than others. Many adjectives that are used to describe taste, for instance, can also be used for smell, but, less likely, for sound. These associations between sensory modalities as they are expressed in language are the topic of this study. We looked at the distribution of the combinations of dominant modalities in pairs of antonymic sensory adjectives (e.g., *sweet–sour*), and how the dominant modality of the adjectives in these pairs differed from that of the adjectives in isolation. In our dataset, there was a sizeable number of pairs consisting of adjectives with differing dominant modalities. Within those pairs, we observed that adjectives with the dominant modality sight can also be used for touch and vice versa. Similarly, adjectives with the dominant modality of smell can also be used for taste and vice versa. Finally, adjectives with the dominant modalities sight and touch can both also be used for hearing and for taste, but not the other way around. These results contribute to our understanding of how language is used to describe sensory experiences, and, with that, how sensory experiences may be shaped by the words that we use to describe them.

Keywords: Antonymy; sensory adjectives; modality dominance

1. Introduction

The sensory system and our perceptual experiences that result from its output play a fundamental role in how we conceive of the world, as well as in the structuring of meanings of words in language. The theoretical claim that meaning in language is grounded in our sensory, and motor systems has by now received substantial support from empirical investigations in psychology, cognitive science, and the language sciences (e.g., Barsalou, 2008, 2020; Bianchi et al., 2011, 2017; Caballero & Paradis, 2020; Louwerse & Connell, 2011; Louwerse & Jeuniaux, 2010; Lynott et al., 2020;

Lynott & Connell, 2009, 2013; Paradis, 2015; Pecher & Zwaan, 2005; Sathian & Ramachandran, 2019; Vigliocco et al., 2009; Winter, 2019; Zwaan, 2004).

Lynott and Connell (2009) conducted a study that provided insight into the use of adjectives to express different sensory modalities, which was later replicated by Lynott et al. (2020) to include the motor system. They asked a panel of 55 participants to rate a set of 423 adjectives with respect to sight, smell, sound, taste, and touch. The following question was posed to the participants: To what extent do you experience something being X (e.g., *tough*) 'by feeling through touch', 'hearing', 'seeing', 'smelling', and 'tasting'? The participants rated each adjective on a six-point scale from 'not at all' to 'greatly'. Three clear findings emerged from this survey. The first was that there were many more adjectives predominantly associated with sight (48%) than with any of the other four modalities. The modality with which the smallest number of adjectives was associated was smell (6%). This is a well-established pattern that has been attested in various languages around the world, but not all (Burenhult & Majid, 2011). There are several reasons for this. From a language point of view the main reason may be that smell is usually described by nouns rather than by adjectives (Hörberg et al., 2022; Paradis, 2015; Paradis & Eeg-Olofsson, 2013). The second finding was that there were no adjectives associated with a single sensory modality in particular. All adjectives were associated with at least two modalities, and 87% of them scored higher than zero on all five modalities. The third finding was that adjectives primarily associated with sound had a higher modality exclusivity than adjectives primarily associated with any of the other modalities. In other words, adjectives that are commonly used to describe sounds are not often used to describe another modality.

The fact that a single adjective can be used to describe different sensory modalities has a number of theoretical and practical implications and raises some interesting questions. The implications are that sensory adjective meaning can only be defined in the presence of the adjective's context, which, in turn, has implications for the comprehension process of the adjective's meaning.[1] From the language user's point of view, the understanding of an adjective is the product of its meaning integrated with a nominal meaning in a given context. Meanings of adjectives are therefore malleable and adaptable to the context and the domain in which they are instantiated. Murphy and Andrew (1993) give *fresh fish* and *fresh shirt* as examples, and argue that language users evoke two readings of *fresh* ('not frozen' and 'unsoiled', respectively) due to the conceptual integration with the nominal meanings. From the point of view of its potential use to evoke sensory meanings, the meaning 'unsoiled' may be instantiated in the domains of smell ('not smelly') and touch ('not wrinkled'), and, *fresh* is associated with at least four of the sensory modalities – if not all five.

Our approach to word meanings is that the range of their readings makes up a total meaning potential in language users' minds (Paradis, 2005). When words, in this case adjectives, are used in communication, only a part of their total use potential is evoked. Cruse (2002) makes use of a spatial metaphor, describing all readings of a word as groupings in conceptual space. The closer the regions are, the more cohesive and less autonomous the meanings. That is, a word's use potential is not an

[1]Incidentally, we point out that the noun that the adjective modifies may not be sufficient for the understanding of the adjective's meaning. The word *smoky* in the phrase '*a smoky dish*' could refer to the dish's taste, smell, or appearance.

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uninterrupted continuum, but rather a range of discontinuously distributed clusters, showing different degrees of cohesiveness and closeness. The direct mapping between words and conceptual structure is then constrained by world knowledge, conventionalized pairings between expressions in language, and conventional modes of thinking in different contexts and situational frames (Fillmore, 1982), where *frame* is to be understood as a cover term for concepts variously known in the literature on natural language understanding as 'schema', 'script', 'scenario', and so forth.

In the past few decades, we have seen an upsurge in research on the topic of the role of the senses in human meaning-making through language (e.g., Bagli, 2021; Caballero et al., 2019; Caballero & Paradis, 2015, 2020; Levinson & Majid, 2014; Majid & Levinson, 2011; Viberg, 2015; Winter, 2019). These works deal with meanings related to the senses from various points of view, such as how sensory experiences are described through language, the sensory vocabulary, and metaphorical uses of sensory meanings.

There is also an increasing body of research in the language sciences and psychology providing evidence of the intimate relationship between the cognitive system and our bodily predisposition and perceptual experiences of the world around us. This intimate relationship is crucial to the cognitive semantics approach and various strands of embodied or grounded cognition (e.g., Beveridge & Pickering, 2013; Fernandino et al., 2015; Kellenbach et al., 2001; Louwerse & Jeuniaux, 2010) and enactivism (McGann & Torrance, 2005; Varela et al., 1991). Both behavioral and neuroscientific research have demonstrated the validity of conceptual perceptual continuity (e.g., see the review article by Barsalou, 2020). Talmy (2000) even used the term *ception* for the continuity of perception and cognition, which also includes aspects of the processing of sensory stimulation, mental imagery, thinking, and affect.

Neurocognitive research has shown that the brain simulates real experiences and actions both when we read, talk and hear about them. For instance, when people encounter the word *lick*, the same motor area in the brain is activated as when they actually perform the action of licking (Pulvermüller, 2003). Similar brain responses have been observed in the areas of taste and smell when we encounter words such as *cinnamon*, *garlic*, or *jasmine* (Barrós-Loscertales et al., 2012; González et al., 2006). Goldberg et al. (2006a)) showed that when participants were asked to generate and compare words based on their overall similarity, the cortical regions activated were those associated with the constitutive sensory features of the described items. Areas involved in smell, taste, and sight perception were activated by words belonging to the category FRUIT, while words belonging to the category CLOTHING activated regions associated with the perception of the human body, action, and biological motion. This finding is in agreement with further evidence that semantic decisions that index tactile, gustatory, auditory, and visual knowledge specifically activate brain regions associated with these sensory experiences (Goldberg et al., 2006b; Spence, 2015). On the one hand, these results support the idea that perceptual and conceptual knowledge have a common neural substrate. On the other hand, they support the hypothesis that *features* of items, not categories *per se*, are represented by disparate brain regions). Thus features (mainly sensory-related) are key. Therefore, the issue of the modality profile of words addressed in this article suggests potentially interesting implications also in terms of brain research.

The undeniable relation between language and sensory experience has led to a growing number of studies in which researchers probe the links between linguistic expressions and different sensory modalities. Two of these studies (i.e., Lynott et al.,

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2020; Lynott & Connell, 2009) have already been cited. Other researchers have provided similar norms for other languages (e.g., Chen et al., 2019; Repetto et al., 2022; Speed & Majid, 2017), for combined concepts and attributes (van Dantzig et al., 2011), and metaphoric language (Winter, 2019). Our goal is to complement these studies with a new dimension, that is, antonymy. To this, we turn to the next section.

2. The present study

In the present study, we do not focus on individual adjectives describing sensory experiences but on combinations of such adjectives, more specifically, antonyms. Antonymy is a binary construal of comparison of some content along a conceptual dimension (Jones et al., 2012; Paradis & Willners, 2011). Antonymic pairs are properties on either side of that dimension separated by a definite boundary or a pivotal neither-nor region (Bianchi et al., 2011, 2013, 2017). The dimension underlying two antonyms can change based on the context. For instance, the dimensions that host HOT–COLD could be TEMPERATURE, in one context, and CRIME (as in *hot* or *cold criminal cases*) or BEHAVIOUR (as in *play hot and cold*) in another. In discourse, the adjectives *hot* and *cold* may obviously form additional antonymic relations with other adjectives along the same or a different dimension. For instance, on the same dimension, we might come across *hot* and *cool,* and along different dimensions such as TASTE, FASHION, and TEMPERAMENT, the antonymic pairings could be *hot–spicy, hot–old-fashioned,* and *hot–calm.* Similarly, *cold* may be on the opposite pole from *friendly, excited*, and *temperate* on the dimensions of PERSONALITY, AROUSAL, and CLIMATE, respectively.

With that, antonyms may offer a complementary perspective on the study of associations between sensory modalities. While previous findings have shown that adjectives may be used for more than one sensory modality, the study of the combinations of antonymic adjectives may reveal which modalities combine easily, and which do not. The dominant modality of the adjective *hot*, for instance, is touch (temperature), and it retains this modality when used as the opposite of the words *cold* or *cool.* However, the modality of *hot* may change to taste when it is used as the opposite of *mild*, suggesting a relatively close association between touch and taste. This association, however, appears to go mainly in one direction because the opposite pattern (i.e., an adjective to describe touch) is not as easy to find.

With this purpose in mind, we will describe the distribution of combinations of the five modalities in antonym pairs, and also that of changes in dominant modality (e.g., from touch to taste in the example above). As a consequence, the study is mainly concerned with antonym pairs consisting of two adjectives with different dominant modalities. We will henceforth refer to these as *cross-modal* pairs, while we refer to pairs consisting of two adjectives with the same dominant modality as *unimodal* pairs. These terms thus indicate that when two adjectives are used as opposites, they are instantiated in a single sensory modality or in multiple sensory modalities, respectively.

From the point of view of associations between the senses, these cross-modal pairs are more interesting than the unimodal pairs because they contain information about how combinations of sensory modalities affect one another, and how these combinations pattern in relation to one another. A finding that some modalities combine more easily than others calls for an interpretation. The

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modalities smell and taste, for instance, may be expected to combine easily in the context of eating and drinking. One reason for that is the interactive effects of smell and taste on how drinks or food are experienced (Caballero et al., 2019). As a consequence, an adjective (e.g., *sweet*) may be used to describe smell as well as taste. At the same time, this expectation may be overly simplistic because there are numerous examples of scents (e.g., flowers) that cannot be associated with a specific taste, and, even within the context of food, there are many examples of tastes (e.g., spiciness, bitterness) that cannot be smelt. Smell and taste, on the other hand, are two modalities that might not readily be transferred to sound, for instance, because most things that smell or taste do not produce sound, or because sound has limited effect on how things taste or smell.

None of the issues mentioned above relate to the degree of modality exclusivity. Beyond doubt, the modality exclusivity of two antonyms will be smaller than that of adjectives presented in isolation. As an example, the adjective *mild* when presented on its own may describe sound, taste, or sight, but when used as the opposite of *spicy* it will only refer to taste. In other words, when presented in pairs, the meaning of one adjective is constrained by the meaning of the other one. Nevertheless, we will also examine and discuss the modality exclusivity of the adjectives antonym pairs and of those that were not.

To obtain answers to the questions outlined above, we combined adjectives from Lynott and Connell's (2009) dataset into pairs that, within a given context, are used as antonyms, looked at the combinations of the dominant modalities of the adjectives in each pair, and compared those to the dominant modality when they combined as members of a pair. All this is described in the following section.

3. Method

Lynott and Connell's (2009) data set consists of 423 adjectives. Each adjective has five average ratings, one for each sensory modality. The rating that is the highest of the five is listed as the dominant modality. In addition, modality exclusivity scores are given which indicate whether the distribution of the five average ratings is roughly equal across the five sensory modalities or rather different. The data set can be downloaded from the journal's website.

All adjectives in this data set were matched in terms of whether they could be used as antonyms. For this, we consulted the online version of Roget's 21st Century Thesaurus (www.thesaurus.com) as well as Power Thesaurus (www.powerthesaurus.org), which list possible antonyms of words. We manually seeded the search boxes of the thesauri with all adjectives from the dataset and selected the antonyms returned by the lists that were also part of the data set. We then also performed web searches with the adjective pairs to ensure that there was additional textual evidence of contexts in which the pairs in the list occurred.

The analysis of the material consists of two parts. In the first part, we describe the combinations of sensory modalities that were represented in our list of antonyms: whether these were the same ('unimodal') or different ('cross-modal'), and which combinations occurred more or less frequently than expected by random selection. In the second part, we categorized the sensory modalities of the antonym pairs ourselves, and identified correspondences between these categorizations and the modalities of the adjectives that the pairs consisted of.

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4. Results

4.1. Material selection

Following the procedure described above, a total of 1,748 antonym pairs were identified, constructed with 369 of the 423 adjectives. Examples of the pairs are *open–quiet*, *clear–nutty*, *hot–musty*. The adjective that combined with most adjectives was *dull*, which occurred in 69 pairs (e.g., *dull–tasty*, *dull–pungent*, *dull–loud*, *dull–bright*). Other prolific adjectives which occurred in many pairs were *soft* (62 pairs, e.g., *heavy–soft*, *harsh–soft*), *smooth* (40 pairs, e.g., *sharp–smooth*, *scaly–smooth*), and *mild* (40 pairs, e.g., *mild–sour*, *mild–noisy*). Some examples of adjectives for which no antonyms were returned by the thesauri were *crunching*, *medicinal*, *strange*, and *plastic*. The dominant sensory modality of the selected adjectives was visual (48%) followed by touch (18%), hearing (17%), taste (11%), and smell (6%). The distribution of these percentages is very close to the one of the entire data set, suggesting no particular bias in the selection.

Figure 1 shows how the adjectives' exclusivity scores were distributed across the dominant modalities within the 369 adjectives that were used as antonyms (dark gray boxes) and within the remaining 54 adjectives for which we did not find a suitable antonym (light gray boxes). As already stated in the original study, the figure shows that adjectives that were most strongly associated with sound were more modality exclusive than adjectives most strongly associated with sight, touch, smell, or taste. In other words, an adjective that is predominantly used to describe sound is less likely to be used to describe sight, taste, smell, or touch. In addition, the figure shows that, within each dominant modality, the adjectives that were used as antonyms were (on average) more modality exclusive than those that were not.

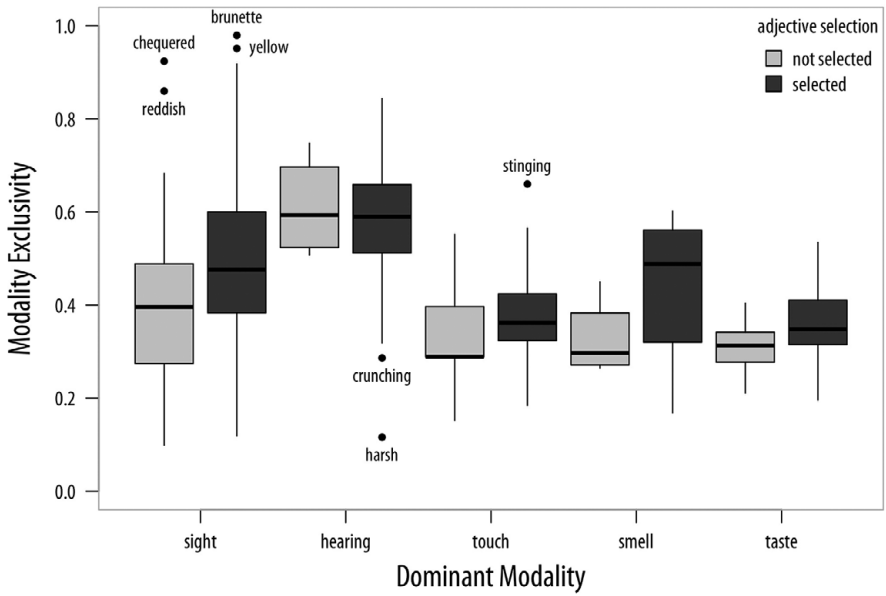

Figure 1. Distribution of modality exclusivity of the adjectives included in the antonym pairs (dark gray boxes) and of those that were not (light gray boxes) across the dominant modalities.

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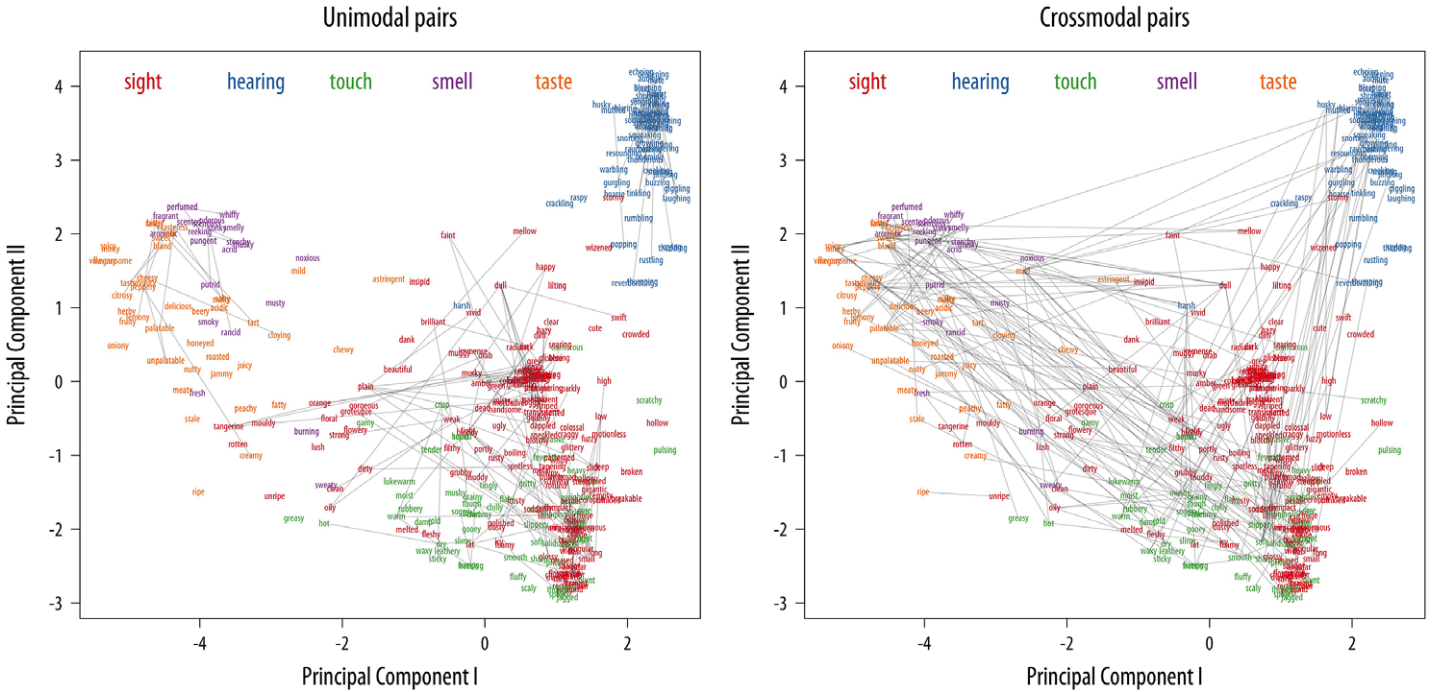

Figure 2. Principal component analysis biplots of the adjective selection with selected pairs of antonyms connected by straight lines within modalities (left panel) or between modalities (right panel).

Table 1. Pairwise comparisons

contrast	estimate	standard error	*z*	*p*
sight–sound	−0.079	0.021	−3.753	0.002
sight–touch	0.123	0.021	5.895	0.000
sight–smell	0.068	0.031	2.162	0.187
sight–taste	0.134	0.023	5.795	0.000
sound–touch	0.203	0.026	7.899	0.000
sound–smell	0.147	0.035	4.230	0.000
sound–taste	0.214	0.028	7.703	0.000
touch–smell	−0.055	0.035	−1.599	0.485
touch–taste	0.011	0.028	0.391	0.995
smell–taste	0.066	0.036	1.839	0.340

The effects on modality exclusivity shown in Fig. 1 were tested statistically with a linear model,[2] using the predictors dominant modality (i.e., the five sensory modalities) and adjective selection (i.e., whether an adjective was included in the selection). The effect of the dominant modality was significant ($F(4,413) = 24.508$, $p = 0.000$) and so was the effect of adjective selection ($F(1,413) = 14.487$, $p = 0.000$). The interaction of these two predictors, however, was not significant ($F(4,413) = 0.336$, $p = 0.854$). The pairwise differences in modality exclusivity between the dominant modalities were tested post hoc using a general linear hypothesis procedure with adjusted *p*-values. The results of that analysis (given in Table 1) showed that modality exclusivity for sound was significantly higher than that for each of the other four modalities. It was also significantly higher for sight than for touch and taste, but not smell. Finally, it was not significantly different between the modalities touch, smell, and taste.

The effect of adjective selection is thought-provoking, since it suggests that the dominant modality of antonymic adjectives is comparatively clear. Possibly, this facilitates the identification of the modality that two opposites have in common. To interpret this result in this direction, we add information about the dominant modalities of the antonymic pairs in the next subsection.

4.2. Dominant modalities of the antonyms

Table 2 shows the proportions and confidence intervals of the dominant modalities of the two adjectives within each pair. The shaded cells on the diagonal contain the pairs consisting of unimodal antonyms, while those in the cells above the diagonal are proportions of cross-modal antonym pairs, as indicated by the row and column labels. The proportions are based on the total number of 1,748 adjective pairs. Within rounding, they add up to 1.

The total number of unimodal pairs is 1,082 or 62% of the total. Examples of these within each of the five sensory modalities respectively are *dark–vivid, noisy–rustling, cold–tepid*, *fresh–musty*, and *citrusy–sweet.* There were 664 cross-modal pairs (38%). Many of these included a combination of sight and touch (e.g., *mellow–rough*), sight

[2]The statistical analyses in this study were performed in R (R Core Team, 2002), using the base package, and the package 'multcomp' (Hothorn et al., 2008).

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Table 2. Observed proportions with 95% confidence intervals in brackets of dominant modality combinations in the antonym pairs

	sight	hearing	touch	smell	taste
sight	.35 [.209–.250]	.04 [.148–.181]	.13 [.153–.186]	.03 [.047–.069]	.06 [.096–.124]
hearing		.11 [.022–.037]	.02 [.049–.071]	.00 [.014–.027]	.01 [.030–.048]
touch			.07 [.023–.039]	.01 [.015–.027]	.03 [.031–.049]
smell				.03 [.001–.006]	.05 [.009–.019]
taste					.04 [.008–.018]

Note: Total *N* equals 1,748.

and smell (e.g., *dirty–fresh*), sight and taste (e.g., *vivid–bitter*), and smell and taste (e.g., *fragrant–stale*).

The proportions in Table 2 thus suggest that antonym pairs are primarily unimodal, but also that some modalities combine relatively easily with one another. We evaluated this claim statistically using a method borrowed from bootstrapping analyses. From the pool of 369 adjectives, 1,746 pairs were randomly selected (with replacement), and the dominant modalities of these pairs were counted. This procedure was repeated 1,000 times with varying proportions in the cells as a result. Finally, the .025 and .975 quantiles within each cell were determined to estimate 95% confidence intervals for the different combinations of the modalities. The lower and upper boundaries of these intervals are given in brackets in the table.

The observed proportions on the diagonal of Table 2 are all considerably higher than the upper boundaries of the confidence intervals. In other words, unimodality was strongly overrepresented among the antonym pairs. The observed proportions above the diagonal are, with one exception, smaller than the lower boundaries of the confidence intervals. Cross-modality, therefore, was underrepresented in the antonym pairs. As an exception, the proportion of antonym pairs consisting of one member with the dominant modality smell and another with the dominant modality taste was higher than expected.

In order to visualize the connections between the antonyms, we plotted the selection of adjectives on the basis of a principal component analysis similar to the analysis that was done by Lynott and Connell (2009). This analysis reduces the five dimensions (modalities) on which the adjectives were measured to two, and shows which adjectives are similar and which are distinct. Such differences and similarities are visualized in a two-dimensional space, as shown in Fig. 2. In this figure, the five modalities are plotted with different colors. In the two panels, random selections of adjective pairs have been connected by straight lines (plotting all connections would have made the plots overly crowded). The left panel shows connections within the modalities, while the right panel shows connections between pairs of modalities. There are relatively few connections going from taste and smell to sound but many to sight and touch, as shown in the right panel. Likewise, most connections departing from sound also go to sight and touch.

4.3. Antonym pair modalities

Table 2 showed that there were a considerable number of pairs consisting of two adjectives that had different dominant modalities. The table did not show, however,

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whether the dominant modality of the two antonyms *as a pair* was the same as that of the first or the second adjective. For instance, there were 64 pairs consisting of one adjective describing sound and the other one describing sight. The combination of the two may have been either sound or sight (or, less likely, one of the other three modalities). If there is an unbalance in the resulting combination of the two modalities (e.g., the dominant modality of most of these 64 antonym pairs was sight) then that suggests that one of the modalities evokes a stronger, more salient meaning to which the other modality adapts (i.e., more easily from sound to sight than from sight to sound).

In order to explore this issue, the dominant modality of the antonym pairs was rated independently by two of the authors. Initially, 1,488 pairs (85%) were given the same dominant modality by both. Together they reconsidered the remaining 260 pairs and agreed on the dominant modality for an additional 119 pairs, totaling 1,607 pairs. The remaining 141 pairs for which there was no consensus were excluded from this part of the analysis. The results are shown in Table 3. In this table, the dominant modalities of the pairs are shown in columns, while those of the two adjectives are given in the rows. The first five rows show the unimodal antonym pairs. The modality of the majority of them is the same as that of the individual adjectives. At the same time, the numbers suggest that modality shifts are possible even within these pairs when they are assessed in combination. Examples of this are the adjectives *hollow* and *clear*, which were both assigned the dominant modality sight, but together have the dominant modality hearing. Another example is the adjectives *clamorous* and *soft*, whose dominant modality is touch, but when used as a pair it is sound.

The remaining rows show the proportions of cross-modal adjective pairs. For most of them, there was a shift in dominant modality for one adjective toward that of the adjective it was paired with. For few of them, the dominant modality of the individual adjectives was not the same as that of the two adjectives as a pair. The eight most frequent shifts in dominant modality have been shaded in Table 3. These are briefly described below.

The shaded cells indicate that there were frequent shifts from sight to hearing, touch, and taste; from touch to sight, hearing, and taste; from taste to smell, and from

Table 3. Dominant modality of the antonym pairs (in columns) in relation to the dominant modalities of the two adjectives (in rows)

	sight		hearing		touch		smell		taste	
sight–sight	573	(0.82)	6	(0.02)	13	(0.06)	0	(0.00)	5	(0.02)
hearing–hearing	0	(0.00)	200	(0.62)	0	(0.00)	0	(0.00)	0	(0.00)
touch–touch	0	(0.00)	2	(0.01)	103	(0.45)	0	(0.00)	5	(0.02)
smell–smell	0	(0.00)	0	(0.00)	0	(0.00)	57	(0.50)	1	(0.00)
taste–taste	0	(0.00)	0	(0.00)	0	(0.00)	1	(0.01)	72	(0.30)
hearing–sight	6	(0.01)	54	(0.17)	1	(0.00)	0	(0.00)	0	(0.00)
touch–sight	80	(0.11)	15	(0.05)	80	(0.35)	2	(0.02)	4	(0.02)
smell–sight	14	(0.02)	0	(0.00)	3	(0.01)	13	(0.11)	8	(0.03)
taste–sight	22	(0.03)	0	(0.00)	2	(0.01)	2	(0.02)	65	(0.27)
hearing–touch	0	(0.00)	31	(0.10)	5	(0.02)	0	(0.00)	0	(0.00)
hearing–smell	1	(0.00)	2	(0.01)	0	(0.00)	0	(0.00)	0	(0.00)
hearing–taste	0	(0.00)	12	(0.04)	0	(0.00)	0	(0.00)	1	(0.00)
touch–smell	0	(0.00)	0	(0.00)	12	(0.05)	5	(0.04)	5	(0.02)
taste–touch	0	(0.00)	1	(0.00)	11	(0.05)	1	(0.01)	38	(0.16)
taste–smell	0	(0.00)	0	(0.00)	0	(0.00)	33	(0.29)	40	(0.16)

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smell to taste. In other words, four of the eight shifts involved sight and touch, smell and taste. These shifts were bidirectional. The remaining four shifts were from sight to hearing and taste, and from touch to hearing and taste, but not the other way around. The modality hearing, finally, did not shift easily toward any of the other modalities.

5. Summary and discussion

Many adjectives can be used to describe more than one sensory experience. A candy can be sweet, but so can smell, sound, or sight. In this study, we examined associations between adjectives describing sensory experiences in language. In particular, we looked at the distribution of sensory modalities in antonyms. We were primarily interested in seeing which modalities attracted one another in antonymic relations (i.e., cooccurred frequently), and which modalities most easily shift when adjectives are engaged in an antonymic relationship.

The first main finding that emerged from the study was that most antonym pairs in our dataset consisted of two adjectives with the same dominant modality, while pairs consisting of two adjectives with different dominant modalities were underrepresented, with the notable exception of the modalities taste and smell. The second finding was that, within antonym pairs, there were frequent shifts from sight to touch and vice versa, from smell to taste and vice versa, from sight to hearing and to taste, and from touch to hearing and to taste. We comment on these findings below.

Adjectives that do not have the same dominant modality do not easily form antonym pairs in language. This suggests a systematicity in antonyms that we did not anticipate in the first place, but which makes sense since words can only be understood as antonyms if they are used to express binary opposition along a single meaning dimension in a given context. Put differently, the context creates the oppositional relation between the adjectives. Within the context of traffic, the colors *red* and *green* may function as opposites in the domain of vision, but not within another context. Similarly, the adjective *sour* may be an antonym of *sweet* within taste, and so may the adjectives *bitter* and *tasteless*, and so on, but *sour* may also be an antonym of *sweet* in the domain of smell.

The only combination of modalities that was not underrepresented was that of taste and smell, suggesting a rather close association between these two sensory modalities. The second part of the analysis also suggested this, because there were frequent shifts from smell to taste and vice versa. This may not be a surprising finding. In the context of food and drinks, the two often go hand in hand. It is difficult to talk about taste without talking about smell. Food that smells good usually also tastes good. At the same time, however, this is an oversimplification. As already pointed out in the introduction, there are many examples of smells in the absence of taste, as there are examples of tastes that do not carry a particular smell. Flowers may smell nice, but that does not mean that they taste good. Food may taste terrible but not smell particularly bad.

There are two further arguments that suggest that the association between smell and taste is not as mutual as is often presumed. The first is that it seems to be the case that there may be quite a few adjectives related to smell only (e.g., *fragrant*, *putrid*, *rancid*, *smelly*, *odorous*), while adjectives describing taste (e.g., *sweet*, *spicy*, *fruity*) can be used to describe smell as well. In other words, sensations of taste are

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easily carried over to smell, but not the other way around. The second argument comes from the results of the second part of the present study. We observed that the dominant modality of many adjectives describing taste in antonyms was either sight or touch, but this was not the case for smell. Intuitively, it is easier to predict that food will taste good (appetizing) by its looks than that a flower will smell good by the way it looks. The relation between touch and taste may be based on similar mechanisms. Food (and even drinks) can be hard, soft, warm, or cold. Interestingly, these (primarily touch) sensations have become associated with taste rather than with smell. This points to the close relation of taste with texture (touch). In fact, one of the components of wine descriptions is mouthfeel, which has to do with the texture of the wine. Taste in this context is a composite of flavor and texture (Caballero et al., 2019). Taken together, these two findings suggest that there are asymmetries in the way perceptions of smell and taste are expressed in language in spite of the fact that these two sensory modalities are so often closely associated with one another.

A bidirectional association between sight and touch (similar to that between taste and smell) was also suggested by the results. In itself, this association may not seem particularly surprising as many sensations of touch are described by the looks of objects (e.g., spiky, thorny), just like the fact that many sensations of smell are described by the objects that produce the smell (yeasty, flowery). A great deal of touch sensations, at the same time, cannot be seen easily. It is impossible to see whether a radiator is hot or cold, whether a flower leaf is sticky or stinging, and whether a cushion is hard or soft. These details can only be established through touch, or they can be filled in by common-world knowledge.

The association between sight and touch is also surprising because sight does not appear to share a similar (i.e., bidirectional) association with smell, taste, or hearing. Any association between the looks of objects or animals, and the sound they produce needs to be learned and cannot be predicted. The same applies to the looks of, for example, food and what it tastes or smells like. In other words, many perceptual experiences related to touch (e.g., *abrasive*, *oily*) can be seen, but so can objects that make sounds or emit smells, or edibles that have a certain taste. Within opposite relations, the association between sight and touch appears remarkably close.

The close association between sight and touch can also be seen in the results of the present study which suggest that adjectives that are predominantly associated with these two modalities are also used to describe sound and taste. The association between sight and taste may be based on the same principle as that between touch and taste: It has come about through experience (e.g., the taste and temperature of ice cream or a cup of tea). However, it appears unlikely that the association between sight and hearing is based on the same principle as that between touch and hearing. The association between what an object (or animal) looks like and what it sounds like is learnt through repeated exposure. But a similar learning process is more difficult to imagine between sound and touch.

Taken together, then, these associations suggest that different mechanisms play a role in how the senses are expressed in language. In this, we acknowledge that the results of this study are limited because they are based on one language only. Additional insights will be provided through the inclusion of other languages and other domains. In the introduction, we referred to some recent data collections that may be used as a basis to do precisely this.

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6. Conclusion

The results of the present study provide new insights about multisensory perceptions through the window of adjectives that may be instantiated in more than one sensory modality both as individual adjectives and as members of antonymic pairs. They suggest that antonymy constrains the meaning of the adjectives in rather systematic ways. In other words, the dimension on which two adjectives form opposites puts a straitjacket on the meaning potentials of the adjectives. This restricts the options for possible instantiations in all five modalities if that is an option for the individual partners in isolation outside the construal of antonymy. The close associative relationship between expressions of, in particular, sight and touch and taste and smell, for instance, differ from sound which is more detached from all other modalities. This makes sense since what you can see you can very often also touch and what you can touch you can always also see, and most of the time what you can taste you can also smell, but not necessarily the other way round. Sound, on the other hand, cannot be seen, touched, tasted, or smelled and therefore it may not pattern in the same way within antonymic relations as the other senses do.

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