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Taste and smell words form an affectively loaded and

emotionally flexible part of the English lexicon

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Abstract

In brain and behavior, gustation and olfaction are closely linked to emotional processing. This paper shows that similarly, words associated with taste and smell, such as "pungent" and "delicious", are on average more emotionally valenced than words associated with the other senses, such as "beige" (visual) and "echoing" (auditory). Moreover, taste and smell words occur more frequently in emotionally valenced phrases, for example, "fragrant" modifies more emotionally valenced nouns ("fragrant kiss") than the visual adjective "yellow" ("yellow house"). It is argued that taste and smell words form an affectively loaded part of the English lexicon. Taste and smell words are also shown to be more emotionally flexible in that words such as "sweet" can be combined with both good and bad nouns ("sweet delight" versus "sweet disaster"), much more so than is the case for sensory words for the other modalities. The paper discusses implications for theories of embodied language understanding.

1. Introduction

Not all sensory modalities are created equal. One dimension along which the senses differ is their involvement with human emotions. For example: Describing something as "yellow" is fairly neutral. However, describing something as "pungent" or "delicious" has an inherent evaluative component. For words invoking visual, auditory and tactile impressions, the evaluative component appears to be optional, i.e., some visual words have strong emotional valence (such as "ugly" or "attractive"), but many others do not (such as "yellow", "large", and "striped"). For olfactory and gustatory terms, on the other hand, the evaluative component appears to be more obligatory (cf. Buck, 1949: 1022; Dubois, 2000; Levinson & Majid, 2014: 411). Even basic perception verbs such as "to smell" and "to taste" are emotionally tainted, for example, "the cheese smells" invokes a negative connotation (Classen, 1993: 53; Dam-Jensen & Zethsen, 2007: 1614; Krifka, 2010).

These linguistic observations correspond to the neurophysiology of taste and smell, the so-called "chemical senses". In the brain, taste is deeply linked with the human reward system (Volkow, Wang & Baler, 2011). Taste and smell are behaviorally and neurally integrated (de Araujo, Rolls, Kringelbach, McGlone & Phillips, 2003; Delwiche & Heffelfinger, 2005; Rolls, 2008; Auvray & Spence, 2008; Spence, Smith & Auvray, 2015) and share close connections with brain areas for emotional processing (Phillips & Heining, 2002; Royet, Plailly, Delon-Martin, Kareken & Segebarth, 2000; Rolls, 2008; Yeshurun & Sobel, 2010). For example, the amygdala, an area known to be involved in emotional processes (e.g., Halgren, 1992; Richardson, Strange, & Dolan, 2004), is also involved in olfaction. The olfactory bulb

projects directly to the amygdala (Price, 1987; Turner, Mishkin & Knapp, 1980), and perceiving pleasant or unpleasant odors and tastes is associated with increased blood flow in this brain area (Zald & Pardo, 1997; Zald, Lee, Fluegel & Pardo, 1998). Moreover, the amygdala exhibits increased blood flow for olfactory, but not for a similar set of visual and auditory stimuli (Royet, Zald, Versace, Costes, Lavenne, Koenig & Gervais, 2000). Phillips and Heining (2002: 204) review the neural evidence and conclude…

> "… that emotion processing and perception of odors and flavors have similar neural bases and that olfactory and gustatory stimuli seem to be processed to a significant extent in terms of their emotional content, even if not presented in an emotional context."

On the behavioral side, studies of odor memories also find close ties between olfaction and emotions (Herz, 1998, 2002, 2007; Herz & Engen, 1996), for instance, odors are particularly strong cues for emotionally potent autobiographical memories (Willander & Larsson, 2006; Chu & Downes, 2000; Herz & Schooler, 2002; Herz, 2004). Waskul, Vannini and Wilson (2009) link odor to the feeling of nostalgia, noting that when people are asked to describe their favorite smell, about 70% of them spontaneously generate responses that relate to their personal biographical histories. Herz (2002: 169) says that "memories evoked by odors are distinguished by their emotional potency, as compared with memories cued by other modalities".

Within an embodied cognition framework, these language-independent behavioral and neurophysiological patterns are expected to have reflections in language structure and use. This is because embodied accounts claim that language and the mind are "structured by our constant encounter and interaction with the world via our bodies and brains" (Gallese & Lakoff, 2005: 456). In this framework, "higher-level" aspects of cognition such as language are seen as exploiting the sensorimotor system for representational purposes (Glenberg, 1997; Barsalou, 1999; Wilson, 2002; Gibbs, 2005; Bergen, 2012). Several empirical studies support the idea that processing sensory words such as "fragrant" and "yellow" involves the activation of sensory brain areas associated with the corresponding modalities (e.g., Pecher, Zeelenberg & Barsalou, 2003; Goldberg, Perfetti & Schneider, 2006; González, Barros-Loscertales, Pulvermüller, Meseguer, Sanjuán, Belloch & Ávila, 2006; Connell & Lynott, 2009, 2010). Given the evidence that the processing of sensory words is at least partially based on the brain structures supporting sensory perception, the involvement of taste and smell in emotional processes is expected to have linguistic reflections.

It has been claimed several times that gustatory and olfactory terms are more emotionally valenced, but these claims have, so far, often rested on intuitions, for example, the word "pungent" appears obviously and intuitively negative. However, in some cases, intuitions about a word's emotional connotation can be misleading (cf. Sinclair, 2004; Hunston, 2007; Morley & Partington, 2009) and nowadays, there are more objective ways of quantifying emotional valence (Pang &

Lee, 2008: Ch. 7; Liu, 2012: Ch. 6; Mohammad, 2012; Warriner, Kuperman & Brysbaert, 2013).

Whether a word does or does not belong to a particular modality was similarly intuited in most past research, i.e., "pungent" appears to be obviously smell-related. But because sensory terms are highly multimodal (Lynott & Connell, 2009; Diederich, 2015), assigning sensory modalities to words is non-trivial. For example, taste terms such as "sweet" can easily be used in olfactory contexts, such as "sweet smell," "sweet fragrance" or "sweet aroma" (Rozin, 1982; Dravnieks, 1985). Should the word "sweet" then be classified as gustatory, olfactory, or both? Hence, objective criteria are needed for assigning sensory modalities to words.

This paper puts the claim that taste and smell words form an affectively loaded part of the English lexicon on a firmer quantitative footing, operationalizing "sensory modality" using a set of modality norms (Lynott & Connell, 2009, 2013; van Dantzig, Cowell, Zeelenberg & Pecher, 2011) and operationalizing "emotional valence" using valence norms (Warriner et al., 2013) and data from a corpus-driven approach (Mohammad, 2012). In addition, the paper shows that the emotional valence of taste and smell words determines their distribution in naturally occurring language data, with taste and smell words occurring, on average, in more emotionally valenced linguistic contexts than words from the other modalities. This addresses what some researchers call the 'semantic prosody' (Sinclair, 2004; Hunston, 2007) or 'evaluative harmony' (Morley & Partington, 2009) of words. The quantitative demonstration of the affective loading of taste and smell words presented in this paper can be seen as supporting theories of embodied cognition,

since it highlights another way through which language (here, lexical structure and word usage) is linked to perceptual processes.

The affective loading of taste and smell words is also important for theories of embodied language understanding for methodological reasons. A prominent paradigm that is used to argue for the modality-specific activation of perceptual content in word processing is the property verification experiment: Pecher, Zeelenberg and Barsalou (2003) demonstrated that when participants verify whether an object has a specific property, they do this slower if adjacent trials switch modalities, e.g., verifying the pair BLENDER-LOUD (auditory) is slower after verifying CRANBERRIES-TART (gustatory) rather than LEAVES-RUSTLING (auditory) (see also Lynott & Connell, 2009; van Dantzig, Cowell, Zeelenberg & Pecher, 2011). Because there are similar modality switching costs in purely perceptual tasks (Spence, Nicholls, & Driver, 2001), the linguistic switching cost has been argued to reflect the activation of modality-specific brain areas. And indeed, Goldberg, Perfetti, and Schneider (2006) have shown that performing such property verifications as CRANBERRIES-TART increases blood flow in brain areas associated with the corresponding sensory modalities (see also González et al., 2006).

However, previous work on the modality switching task has ignored the emotional dimension of sensory words—even though it is known that participants are slower to process a positive/negative word after having been primed with a word of opposite valence, so-called "affective priming" (Fazio, Sanbonmatsu, Powell & Kardes, 1986). In modality switching studies such as Pecher et al. (2003), a switch from the word "putrid" to the word "sweet" might be slow not because of a switch

from olfaction to taste, but because of a switch from negative to positive valence. If, as this paper will demonstrate, the modality of a sensory word is indeed associated reliably with specific emotional features, it is necessary to account for concomitant valence switches in the modality switching paradigm.

Another point of relevance of the emotional dimension of sensory words is demonstrated by Citron and Goldberg (2014), who studied whether metaphorical language is overall more emotionally engaging. In support of this view, the authors found that metaphorical sentences elicited more activation in the left hippocampus and parahippocampus, including the amygdala. However, all the metaphorical sentences in Citron and Goldberg (2014) were taste-related (e.g., "She received a sweet compliment"), which invites the possibility that the amygdala activation is in part mediated through connections between taste and emotional valence, rather than being due to the emotionality of metaphors per se. Similarly, in a meta-analysis of studies on metaphorical language processing, Bohrn, Altmann and Jacobs (2012) found that overall, metaphorical language often activates the left amygdala, however, they did not control for whether the investigated metaphors were sensory metaphors—even though many metaphors do indeed evoke modality-specific sensory content (Caplan, 1973; Williams, 1976; Marks, 1982; Matlock, 1989; Sweetser, 1990; Shen & Gil, 2007; Cacciari, 2008; Ibarretxe-Antuñano, 2013).

Finally, both sensory modalities and emotions have been linked to word processing speed. For example, emotional words are processed more quickly than neutral words (Kousta, Vinson & Vigliocco, 2009; Kousta, Vigliocco, Vinson, Andrews & Del Campo, 2011; Kuperman, Estes, Brysbaert & Warriner, 2014).

Similarly, more imageable words are processed faster (e.g., Swaab, Baynes & Knight, 2002), as well as words that have overall more perceptual content (Connell & Lynott, 2012). On the other hand, words related to the tactile/haptic modality may be processed more slowly (Connell & Lynott, 2010). Amsel, Urbach and Kutas (2012) have also shown that words rated high on taste pleasantness are processed more quickly. The speed of processing words is thus co-determined both by the sensory modality and the emotional valence of a word, which calls for considering both of these factors together.

In addition to demonstrating the overall affective loading of taste and smell words, the paper also describes a novel fact about the English sensory vocabulary, namely, that taste and smell words are more emotionally flexible, i.e., a taste and smell word is likely going to be used in *both* positive and negative contexts. This emotional variability is predicted based on past research on sensory perception. The perceived pleasantness of taste and smells changes as a function of internal body states, such as satiation (Cabanac, 1971; Rolls, 2008), for example, participants that initially rated a sweet smell as positive perceived it to be less pleasant after being injected with glucose (Cabanac, Pruvost, & Fantino, 1973). The valuation of tastes and smells is furthermore easily modified through verbal labels and packaging (Case, Repacholi & Stevenson, 2006; Lee, Frederick & Ariely, 2006; Djordjevic, Lundstrom, Clement, Boyle, Poulio & Jones-Gotman, 2008; Liem, Miremadi, Zandstra & Keast, 2012). Finally, since the hedonic dimension of many tastes and smells is learned rather than innate, there also is strong intra- and extra-cultural variability in the perceived pleasantness of certain tastants and odorants (e.g., Herz, 2002).

Given these studies, and given the embodied cognition idea that such perceptual patterns are reflected in language use, it is expected that taste and smell words are more flexible with respect to their valence. This is exemplified by the common saying "sweet stink of success", which combines a highly positive adjective ("sweet") with a highly negative noun ("stink"). Analogous expressions in the other modalities, such as "ugly beauty" or "noisy harmony", should be less common.

2. Methods

2.1. Modality norms

The analysis correlates modality norms (Lynott & Connell, 2009, 2013; van Dantzig et al., 2011) with measures of valence (Warriner, Kuperman & Brysbaert, 2013; Mohammad, 2012). This is done for adjectives, nouns and verbs. The adjective data comes from Lynott and Connell (2009), who asked fifty-five native speakers of English to judge a set of 423 object properties on each of the five "common senses" (vision, hearing, touch, taste, smell). The word with the highest visual, auditory, tactile, gustatory and olfactory strength ratings are "bright", "barking", "smooth", "citrusy" and "fragrant", respectively. The highest perceptual strength rating of a word determines a word's "dominant modality". Lynott and Connell (2013) additionally normed 400 nouns, with "reflection", "sound", "hold" (noun), and "taste" being the most unimodal visual, auditory, tactile and gustatory words—the only two words that were rated as being dominantly olfactory were "air" and "breath", which are only indirectly associated with olfaction.

To complement these adjective and noun norms, and to show that the affective loading of taste and smell words is indeed a general property of the English lexicon, an additional set of verb norms was collected for this study. Following a frequently used approach (see Lynott & Connell, 2009; Strik Lievers, 2015), a list of sensory words was constructed by first selecting a small group of target words, namely, the basic perception verbs "see", "look", "hear", "listen", "sound", "feel", "touch", "taste" and "smell" (following Viberg, 1983). Then, several online thesaurus lists were consulted to expand on this set of verbs by looking up their synonyms (macmillandictionary.com, collinsdictionary.com, wordreference.com, thesaurus.yourdictionary.com, and thesaurus.com). This lead to a list of 187 candidate verbs for norming. To complement this set, 113 verbs were randomly selected from the English Lexicon Project[1] (Balota, Yap, Hutchison, Cortese, Kessler, Loftis, Neely, Nelson, Simpson & Treiman, 2007).

The total set of 300 verbs were randomly ordered and split into 10 lists with 30 verbs each. Ninety-one native speakers of American English (40 female, 51 male, average age 31), recruited via Amazon Mechanical Turk, received 0.65 USD reimbursement to norm one list each (completion rate was 85%; average survey duration was 9 minutes). Only data from participants who completed at least 80% of each list was analyzed; yielding a dataset with a total of seventy-two native speakers of American English. Table 1 shows exemplary verbs and their dominant modalities. Unimodality was calculated using the "modality exclusivity" measure introduced in Lynott and Connell (2009).

[1] Verbs were chosen that were above the median word frequency from the American English SUBTLEX subtitle corpus (Brysbaert & New, 2009).

For English adjectives, van Dantzig et al. (2011) collected an additional norming set—the interpretation of the findings reported in this paper does not change if this different dataset is used. All reported results will be based on the Lynott and Connell (2009) adjectives. Thus, the total set of words analyzed in the body of the text contains 423 adjectives, 400 nouns and 300 verbs (1,123 words in total).

2.2. Valence norms

In the past, judgments about whether a sensory word has a positive or negative connotation were made subjectively by the researcher. But the generality of such judgments is questionable since different people have different intuitions, and the emotional connotation of a word can sometimes only be inferred from a word's context. For instance, the word "banker" was rated to be neutral by the participants of Warriner et al. (2013), but it is one of the most negative words in the Twitter Emotion Corpus (Mohammad, 2012).

In this paper, two approaches are used to quantify emotional valence. First, the valence norms collected behaviorally by Warriner et al. (2013). In this norming study, 723 US American participants rated a set of 13,915 words on a scale from 1 ("unhappy, annoyed, unsatisfied, melancholic, despaired, bored") to 9 ("happy, pleased, satisfied, contended, hopeful"). The most positive word in this dataset is

"vacation" (with a value of 8.53); the most negative is "pedophile" (with a value of 1.26).

A second way to compute emotional valence is based on text co-occurrences with paradigmatically positive or negative words. Mohammad (2012) compiled a dataset of valence norms for 54,129 words and hashtags based on the emotional content of Twitter tweets such as the following (p. 246):

We are fighting for the 99% that have been left behind. #OWS #anger

In this example, *#anger* specifies the emotional undertone for the message. Words that frequently occur in tweets together with negative emotional hashtags, such as *#sadness* or *#disgust*, are likely negative. Words that frequently occur in tweets together with positive emotional hashtags, such as *#joy*, are likely positive. The resulting Twitter Emotion Corpus Lexicon (Mohammad, 2012) has "elegant" as the most positive word (with a value of +5.7) and "ipad2" as the most negative word (with a value of -6.6).

For both the Warriner et al. (2013) and the Mohammad (2012) valence norms, an additional "absolute valence" measure was calculated, quantifying the degree of overall "affective loading", i.e., the emotional involvement of a word disregarding the sign of the valence. This was done by subtracting the mean of all valence ratings from each rating and then taking the absolute value. For example, "happiness" has a mean valence rating of 8.48; "guillotine" has a mean valence rating of 1.63. When subtracting the mean valence of all words and taking the absolute

value, these two words have the same "absolute valence" (3.42), indicating that they are both relatively emotional words, regardless of the opposite sign of their valences. Words ranking low on this absolute valence score are relatively more neutral, such as "dormitory", "adjoining" or "steward". For the Warriner et al. (2013) valence data, this absolute valence score ranges from 0 to 3.8; for the Mohammad (2012) data, it ranges from 0 to 7.5.

The body of the text focuses on the analysis of the Warriner et al. (2013) and Mohammad (2012) valence norms, but it should be noted that the basic findings replicate with an additional third way of calculating valence that uses the SentiWordNet 3.0 norms (Esuli & Sebastiani, 2006; Baccianella, Esuli & Sebastiani, 2010).

2.3. Statistical analysis

In the first set of analyses, the modality norms were associated with the two sets of valence norms. In the second analysis, the register-balanced 450 million word Corpus of Contemporary American English (COCA, Davies, 2008) was used to assess whether the phrasal contexts in which modality-specific words occur are more or less valenced. This was done using only the adjectives, focusing on adjective-noun pairs such as "fragrant kiss" or "sweaty prison". In the third analysis, the emotional variability of the nouns co-occurring with the target adjectives was analyzed.

All analyses were conducted with R (R Core Team, 2015) and the R packages "lme4" (Bates, Maechler, Bolker, & Walker, 2015), "MuMIn" (Bartoń, 2015), "effsize" (Torchiano, 2015) and "dplyr" (Wickham & Francois, 2015). The data and analyses

scripts are available on a publicly accessible Github repository:

https://github.com/bodowinter/affect_modality

Valence norms are analyzed using simple one-way ANOVAs with a categorical predictor "modality" (vision, hearing, touch, taste, smell) that is based on the "dominant modality" classification according to Lynott and Connell (2009), i.e., the highest modality score determines a word's modality. In addition, the following planned post-hoc comparisons were conducted: For the raw valence measure (ranging from positive to negative), the difference in valence between olfaction and gustation was tested, since it has been claimed that olfactory words are more negative than gustatory words (Buck, 1949: 1022-1032; Rouby & Bensafi, 2002: 148-149; Jurafsky, 2014: 96-98; Classen, 1993: 53; Allan & Burridge, 2008: Ch. 8; Krifka, 2010). Second, for the absolute valence measure, the "chemical senses" (gustation and olfaction) are compared against all the other sensory modalities, looking to see whether taste and smell have higher overall emotional valence.

3. Results

3.1. Sensory words and emotional valence

The first analysis focuses on the valence of modality-specific words. 904 of the 1,123 sensory words are represented in the valence norms of Warriner et al. (2013) (80.5%), and 960 of them are represented in the valence norms of Mohammad (2012) (85.5%). A simple two-way ANOVA with the factors modality and part-of-speech (POS: nouns, verbs, adjectives) revealed significant main effects of modality ($F_{(4, 889)} = 3.78$, $p = 0.0047$) and POS ($F_{(2, 889)} = 9.6$, $p < 0.0001$), in addition to a

significant modality * POS interaction (F (8, 889) = 3.54, p = 0.00049). The corresponding linear model fits for each sensory modality are shown in Figure 1a. Overall, this model accounted for 5% of the variance in valence norms (adjusted R^2 = 0.05).

On average, gustatory words had the highest positive valence (5.59) and olfactory words were most negative (4.82), with the other modalities being in between these two extremes (vision: 5.40, hearing: 5.21, touch: 5.09). Moreover, nouns were more positively valenced (5.55) than verbs (5.21) than adjectives (5.07). The significant interaction was partly driven by the fact that the negative/positive difference between olfactory and gustatory words is most pronounced for adjectives. Moreover, the meaning of "olfaction" is somewhat different for the noun norms (Lynott & Connell, 2013), which only had "air" and "breath" as olfactory words, both of which are relatively positive. A planned post-hoc comparison between olfactory and gustatory words revealed a significant difference (t (69) = 2.04, p = 0.046, Cohen's d = 0.49), with gustatory words being more positive (M = 5.6, SD = 1.7) than olfactory words (M = 4.8, SD = 1.5).

(INSERT FIGURE 1 ABOUT HERE)

Figure 1b shows the predicted absolute valence based on the Warriner et al. (2013) dataset. Again, there was a significant effect of modality (F (4, 889) = 4.99, p = 0.0005) and POS (F (2, 889) = 5.96, p = 0.0027), but this time, no modality * POS interaction (F (8, 889) = 1.48, p = 0.16), indicating that the modality differences in

absolute valence were approximately the same across nouns, verbs and adjectives. Overall the model accounted for 3.2% of the variance in absolute valence. Olfactory (1.46) and gustatory (1.37) words had the highest average absolute valence, followed by auditory (1.15), haptic (1.06) and visual words (1.01). A planned post-hoc comparison revealed that olfaction and gustation differed significantly in absolute valence (t (902) = 3.99, p < 0.0001, d = 0.49), with words for olfaction and gustation being overall more valenced (M = 1.4, SD = 0.77) than words associated with the non-chemical senses (SD = 0.76).

For the Mohammad (2012) valence norms (negative to positive), there was no effect of modality (F (4, 945) = 1.59, p = 0.17; overall adjusted R^2 = 0.02), however, an effect of modality was obtained for absolute valence (F (4, 945) = 4.7, p = 0.0009; R^2 = 0.05). A planned post-hoc comparison revealed no significant difference in valence for gustation and olfaction (t (79) = 1.57, p = 0.12, d = 0.36), with gustatory words only being slightly more positive (0.34, SD = 1.1) than olfactory words (-0.08, SD = 1.24). However, there was a significant difference in absolute valence between the chemical and the non-chemical senses (t (958) = 4.05, p < 0.0001, d = 0.47). Together, gustatory and olfactory words had an absolute valence of 0.87 (SD = 0.78), compared to only 0.58 (SD = 0.59) for words associated with the non-chemical senses. This analysis used a different dataset (Mohammad, 2012) to replicate the main finding that taste and smell words are overall more emotionally valenced than words for the other sensory modalities.

In order to truly assess whether a word is used for emotional functions, the valence of the word itself may be informative, but the context in which the word is

commonly used should be a better indicator of a word's emotional valence, in line with the idea that there is 'semantic prosody' or 'evaluative harmony', with words having preferences for positive or negative contexts (Sinclair, 2004; Morley & Partington, 2009).

3.2. Adjective collocates

To test the idea that taste and smell adjectives are more likely to be paired with highly valenced nouns, every two-word combination for all Lynott and Connell (2009) adjectives was extracted from the COCA corpus, for example, the adjective "cloying" occurred together with the noun "smell" (valence = 6.39) seven times in COCA, and with the noun "sweetness" eight times (7.37), among many other co-occurrences. All the noun valences were averaged, yielding a new number, in this case 6.06, the mean valence of the noun contexts of the word "cloying". This mean was computed in a frequency-weighted fashion, i.e., adjective-noun pairs that are relatively more frequent contribute more towards an adjective's "context valence". With this analysis, it is possible to compute the context valence for words that have no valence scores themselves. The word "cloying", for instance, is not represented in the Warriner et al. (2013) data but has a context valence score because valence norms exist for many of the word's noun collocates.

A total of 149,387 adjective-noun pairs were analyzed. These were all the adjective-noun pairs that feature an adjective from Lynott and Connell (2009) occurred. The Warriner et al. (2013) valence data exists for ~80% of the nouns in these pairs; the Mohammad (2012) data exists for ~82%. COCA is part-of-speech

tagged, and only adjective-uses with singular noun co-occurrences were analyzed. Context valence could be computed for 405 of the 423 adjectives from Lynott and Connell (2009), a coverage of 96%.

For raw context valence computed with the Warriner et al. (2013) norms, there was a significant effect of the adjective's dominant modality (F (4, 400) = 17.03, p < 0.0001, R^2 = 0.14). The same was the case for the Mohammad (2012) norms (F (4, 400) = 9.33, p < 0.0001, R^2 = 0.077). Planned post-hoc comparisons revealed that for the Warriner et al. (2013) norms, gustatory words were more positive than olfactory words (t (70) = 4.33, p < 0.0001, d = 1.07). Whereas gustatory words had an average context valence of 5.8 (SD = 0.3), olfactory words had an average context valence of 5.5 (SD = 0.3). For the Mohammad (2012) norms, there was no significant difference in context valence between gustatory words (0.4, SD = 0.27) and olfactory words (0.41, SD = 0.98) (t (70) = 0.12, p = 0.90, d = 0.03). Figure 2a shows the linear model fits of the context valence for the Warriner et al. (2013) norms.

(INSERT FIGURE 2 ABOUT HERE)

For the absolute valence of the context, there were significant effects for the Warriner et al. (2013) (F (4, 400) = 25.06, p < 0.0001, R^2 = 0.19) and the Mohammad (2012) data (F (4, 400) = 13.05, p < 0.0001, R^2 = 0.11). Planned post-hoc comparisons revealed that gustatory and olfactory words were significantly more valenced than words for the non-chemical senses for both the Warriner et al. (2013)

data (t (403) = 7.52, p < 0.001, d = 0.98) and the Mohammad (2012) data (t (403) = 7.07, p < 0.0001, d = 0.92). For the Warriner et al. (2013) data, words associated with the chemical senses had an average absolute context valence of 1.16 (SD = 0.19), compared to 0.99 (SD = 0.17) for the non-chemical senses. For the Mohammad (2012) data, the difference was 0.8 (SD = 0.52) to 0.58 (SD = 0.1). Figure 2b shows the predicted linear model fits for the absolute context valence.

To further highlight how taste and smell words specialize in emotional language, the relationship between word frequency and absolute valence was analyzed for each sensory modality. This analysis addresses the question: Is it the case that the most frequent collocates of adjectives from the chemical senses are the more emotionally valenced ones, compared to less frequent adjective-noun combinations that may be more neutral? For example, the word "pungent" modified the highly negative word "odor" 52 times in the COCA dataset; it modified the relatively neutral word "vinegar" only 1 times.

A linear mixed-effects regression analysis was fitted to the log frequency of each pair, with modality and absolute valence as fixed effects (including their interaction) and adjective and noun random intercepts as well as by-adjective random slopes for absolute valences. Crucially, there were significant interactions between modality and valence for both the Warriner et al. (2013) data (likelihood ratio test: χ^2 (4) = 16.65, p = 0.002; marginal & conditional R^2 = 0.004, 0.19) and the Mohammad (2012) data (χ^2 (4) = 37.02, p < 0.001; marginal & conditional R^2 = 0.004, 0.18). Figure 3 visualizes the predicted relationship between valence and frequency for each modality. The absolute valence slopes for olfactory and gustatory

words (highlighted in bold) are more positive, indicating that only for these words were more valenced contexts also more frequent.

(INSERT FIGURE 3 ABOUT HERE)

3.3. Emotional flexibility

As stated in the introduction, there is evidence to suggest that taste and smell as perceptual modalities are malleable with respect to the emotional valence of a sensory stimulus, being susceptible to internal (e.g., body states) and external (e.g., verbal suggestion) influences. Given the embodied cognition idea that word use mirrors such language-external perceptual factors, this predicts that taste and smell *words* should also be more emotionally flexible. To assess this, the adjective collocate analysis from the last section was repeated, except that this time, not the average valence was calculated, but the standard deviation across the noun contexts. Sensory adjectives that occur together with both positive and negative nouns are going to have a higher valence standard deviation than sensory adjectives that occur together with only very positive or only very negative words. For example, in COCA, the gustatory word "sweet" occurs in the expressions "sweet delight" (noun valence = 8.21), "sweet joy" (8.21) and "sweet sunshine" (8.14), but also "sweet death" (1.89), "sweet disaster" (1.71) and "sweet nausea" (1.68). Computing the standard deviation across all of these noun valences (8.21, 8.14 etc.) yields a measure of how much "sweet" occurs in both positive and negative noun contexts. For "sweet", the standard deviation is 1.26 (for the Warriner et al. 2013

norms), in comparison to only 1.06 for the less emotionally variable visual word "yellow".

A simple one-way ANOVA revealed a significant effect of modality for the Warriner et al. (2013) norms (F (4, 398) = 20.77, p < 0.001; R^2 = 0.16) and the Mohammad (2012) norms (F (4, 398) = 9.39, p < 0.001; R^2 = 0.08), displayed in Figure 4. Post-hoc comparisons of chemical versus non-chemical senses revealed that taste and smell words had significantly higher context standard deviations than sensory words associated with the non-chemical senses for both the Warriner et al. (2013) data (t (401) = 3.33, p = 0.0009, d = 0.44) and the Mohammad (2012) data (t (401) = 6.04, p < 0.0001, d = 0.79). For the Warriner et al. (2013) data, gustatory and olfactory words had an average context variability of 1.18 (SD = 0.22), compared to 1.09 (SD = 0.19) for the non-chemical senses. For the Mohammad (2012) data, the difference was 0.95 (SD = 0.2) to 0.81 (SD = 0.18).

(INSERT FIGURE 4 ABOUT HERE)

As revealed by Figure 4, the auditory modality also had high context variability. Examples of this are "howling laughter" versus "howling scream" and "hoarse cheer" versus "hoarse cry". Auditory words are more exclusive to their own modality (Lynott & Connell, 2009, 2013; Louwerse & Connell, 2011) and almost any auditory word can be used to modify neutral words (such as "sound" and "voice"), positive words ("laughter") and negative words ("noise" and "cry"). The emotional flexibility of taste and smell words appears to be of a more general kind, with taste

and smell adjectives modifying many nouns that are not particularly sensory-specific, such as "sweet disaster".

4. Discussion

The preceding analyses revealed that there is a probabilistic tendency for words associated with the chemical senses to be more strongly valenced, as well as to appear in more emotionally valenced contexts. Thus, perceptual language relates to emotions, mirroring the ways through which the different sensory modalities are connected to emotional processing in the human brain and in behavior. The present findings fit in with past research linking the chemical senses to emotional valence both behaviorally (e.g., in memory, Herz, 2007) and neuro-functionally (e.g., Zald & Pardo, 1997; Zald, Lee, Fluegel & Pardo, 1998). The results furthermore suggest that differential expression of emotional valence across modalities is something that should be considered when conducting studies of sensory metaphors (e.g., Citron & Goldberg, 2014) and property verifications (e.g., Pecher et al., 2003).

Some taste and smell words have dictionary entries that explicitly mention a positive or negative meaning, e.g., the MacMillan dictionary definition of "fragrant" is "with a pleasant smell". So how does the present analysis go beyond merely re-expressing what is already encoded in dictionaries? Many words have semantic prosodies that are subtle and are often not encoded in a dictionary (Dam-Jensen & Zethsen, 2007). For example, of the gustatory and olfactory words considered in this chapter, 57% of them have dictionary entries in the MacMillan Online Dictionary that do not mention any evaluative connotation. "Minty" (positive valence: 7.0) and

"fruity" (positive: 6.71) are two examples of words that are valenced by the measures considered here but that do not have connotations listed in MacMillan. Similarly, the highly negative adjectives "fatty" (2.38) and "alcoholic" (2.49) have descriptive dictionary entries such as "containing a lot of fat". Thus, the approach used in this chapter is able to get at subtle affective meaning. Moreover, distributional patterns such as the fact that taste and smell words occur in more emotionally variable contexts are not encoded in dictionaries either.

The results reported in this paper furthermore suggest that smell words are more negative and occur in negative contexts than taste words. This is a quantitative confirmation of an observation that is frequently made in linguistics (cf. Buck, 1949: 1022-1032; Rouby & Bensafi, 2002: 148-149; Jurafsky, 2014: 96-98; Classen, 1993: 53; Allan & Burridge, 2008: Ch. 8; Krifka, 2010). What explains the affective polarization of taste and smell? Classen (1993: 53) explains this as follows: "We can choose our food, but we cannot as readily close our noses to bad smells" (see also Krifka, 2010). This would entail that on average, humans are more likely to be exposed to unpleasant smells than to unpleasant tastes. Moreover, it is generally the case that things that we can exert control over are more liked than things that evade our control (see e.g., Casasanto & Chrysikou, 2011). Finally, scholars in the West have long since regarded smell as an "animalistic" or "primitive" sense (Le Guérer, 2002) and part of these cultural preconceptions might be shared with laymen, hence tainting smell negative.

It is noteworthy that the effect sizes of the results were rather small for the valence and absolute valence analyses performed on individual words ($R^2 \sim 5\%$;

Cohen's d ∼0.5), but much larger for the same analyses performed on the adjective-noun pairs (R^2 ∼20%; Cohen's d ∼0.9-1.0). The large effect size for the context analysis suggests that knowing a word's sensory modality is quite predictive of which type of contexts (i.e., positive/negative, high valence/low valence) it occurs in. There could be several reasons for the fact that the context results are stronger. One potential explanation is that valence effects might be strongest for adjective-noun pairs because adjectives are frequently used in evaluating objects and their qualities (e.g., Fenko, Otten & Schifferstein, 2010). Moreover, corpus linguists researching "semantic prosody" (e.g., Sinclair, 2004; Hunston, 2007; Morley & Partington, 2009) claim that a considerable degree of a word's connotation is only revealed by looking at the types of contexts a word occurs in, hence, the context analysis simply might yield a more accurate estimate of a word's connotation.

On top of these considerations, there is, however, a purely statistical reason for the stronger context results. For many of the adjectives from Lynott and Connell (2009), there is no corresponding valence data in the Warriner or Twitter datasets, for instance, the words "acrid" and "cloying" are not in any of these datasets. However, valence data exists for many of the words that co-occur together with "acrid" and "cloying", and so it turns out that these words have a contextual valence value for each of the two datasets even though there is no valence data associated with the word itself. Thus, the number of words considered in the context analyses is larger than the number of words considered in the analyses of the words themselves. This gives the context analyses more statistical power. Thus, to get a

larger coverage of valence norms, one can look at the words that *co-occur* with a given word, rather than at the valence rating of the word itself.

The evidence presented in this paper can be interpreted as showing an embodied effect on the emotional structure of the English lexicon. Crucially, the evidence for taste and smell being "emotional" modalities comes from studies that do not necessarily involve language, such as neuroimaging studies of taste and smell stimuli. Similar to the reasoning that the modality switching costs in conceptual processing (Pecher et al., 2003) are evidence for embodied language understanding because they also emerge in purely perceptual processing (Spence et al., 2001), the close correspondence between non-linguistic studies of taste and smell and the linguistic structures observed here suggests that language mirrors embodied patterns. The correspondence between factors traditionally thought of as language-external and the linguistic effects observed here not only involves the overall emotional involvement of taste and smell words, but also their emotional flexibility—there is neural and behavioral evidence for the emotional flexibility of taste and smell as perceptual modalities, which this paper showed to be reflected in the emotional context variability of the corresponding sensory words.

Another aspect of the results actually supports this embodied perspective, which is the fact that taste and smell behave linguistically similar. The perception of "flavor" arises from the interaction of taste and smell, and odors reach the olfactory bulb also through the back of the mouth (Auvray & Spence, 2008; Spence et al., 2015). Eating necessarily involves smelling (Mojet, Köster, & Prinz, 2005) and not surprisingly, taste and smell are neurally integrated, sharing overlapping brain

networks (de Araujo et al., 2003; Delwiche & Heffelfinger, 2005; Rolls, 2008). Thus, the fact that taste and smell language behave similarly at all can be seen as a reflection of the underlying integration of taste and smell as perceptual modalities.

The present results also support aspects of Max Louwerse's Symbol Interdependency Theory (Louwerse, 2011; Louwerse & Connell, 2011). According to this theory, language understanding simultaneously involves "embodied cognition" (i.e., perceptual simulation) and "symbolic cognition" (i.e., the processing of linguistic associations, such as when "nurse" primes "doctor"). In the modality switching paradigm, a switch from an auditory trial (LEAVES-ROUSTLING) to another auditory one (BLENDER-LOUD) is thought to be easy not necessarily just because accessing words such as "rustling" and "loud" activates the corresponding embodied auditory concepts, but also because these words are linguistically associated with each other (Louwerse & Connell, 2011). A similar proposal is put forth by the Language as Situated Simulation (LASS) theory (Barsalou, Santos, Simmons & Wilson, 2008).

In order for lexical effects to account for any variance in embodied cognition studies, the lexical associations need to mirror embodied relations in the first place. In effect, Louwerse's "symbolic cognition" is embodied cognition channeled through language structure—only because words linguistically cluster together in ways that mirror perceptual distinctions (e.g., auditory words cluster with other auditory words) can language explain some of the results in embodied tasks such as the modality switching paradigm. The present results are located at the level of linguistic structure and language use, looking at the valence of words in the English

lexicon and how these words are used. However, given the fact that the embodied

relations reflected in language can influence linguistic processing (Louwerse, 2011;

Louwerse & Connell, 2011), the structural and usage differences analyzed here have

implications for language processing as well.

Finally, how do the present results fit into the literature on differences

between the sensory modalities? Several authors in linguistics and anthropology

have tried to argue for different hierarchies of the senses (e.g., Williams, 1976;

Viberg, 1983; Shen & Gil, 2007). A recurrent theme across this literature is that

vision is thought to be a dominant sensory modality, as opposed to particularly the

chemical senses, such as smell (for critical discussions, see Majid & Burenhult, 2014

and San Roque et al., 2015). The idea that such a ranking should be universal and

valid across the board has been attacked based on the analysis of word frequencies

of perception verbs across cultures, which show culturally specific rankings for the

non-visual senses (e.g., San Roque et al., 2015). And the idea of a universal ranking

has also been attacked based on anthropological and experimental research

showing that particular modalities are more important in certain cultures (for

example, Burenhult & Majid, 2011; Majid & Burenhult, 2014; Lewis, 2009, among

many others). The present research suggests another way in which across-the-

board generalizations such as "modality X is more dominant than modality Y" need

to be qualified: The dominance of a sensory modality can only be defined with

respect to a certain domain, and not necessarily across the board. In the present

study, taste and smell words were shown to specialize into relatively more

emotional contexts, forming a subpart of the English lexicon that is statistically

associated with more affectively loaded content. So while it may well be true that perceptual language is statistically more frequent or more differentiated for modalities such as the visual one (San Roque et al., 2015), the more "affective" part of the lexicon is relatively more dominated by odor and gustatory terms.

Acknowledgements

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Tables

Modality	Frequent	Infrequent	Unimodal	Multimodal
Visual	*see, look*	*google, gaze*	*espy*	*experience*
Tactile	*get, give*	*gabble, peal*	*grope*	*sense (v.)*
Auditory	*know, say*	*caw, boom*	*listen*	*trigger*
Gustatory	*eat, taste*	*savour, swill*	*sip*	*sample*
Olfactory	*smell, breathe*	*exhale, stench (v.)*	*scent (v.)*	*exhale*

Table 1: Examples of verbs according to the modality norms collected for the present study; modality ratings are much more interpretable for high frequency words as shown by "to gabble" and "to peal", which were misinterpreted to be primarily tactile words (although "gabble" received comparatively strong auditory ratings as well), presumably because their meaning was not known enough to participants
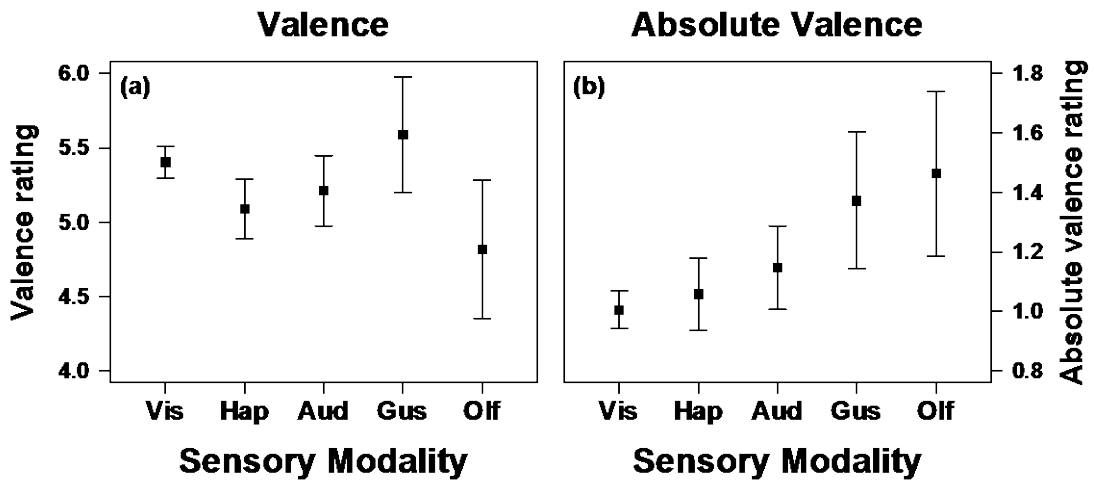
Figure captions

Figure 1: Linear model fits and 95% confidence intervals for (a) valence and (b) absolute valence for the Warriner et al. (2013) dataset
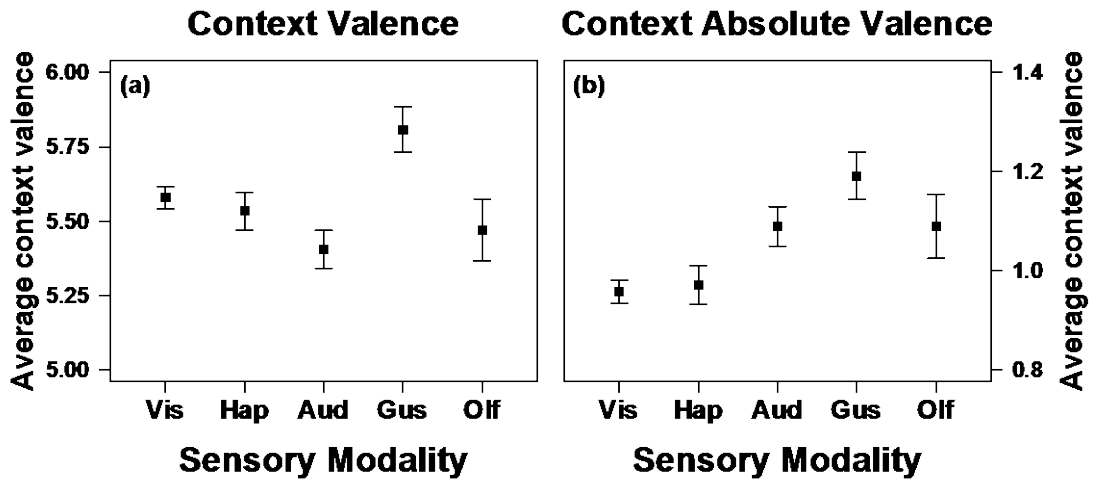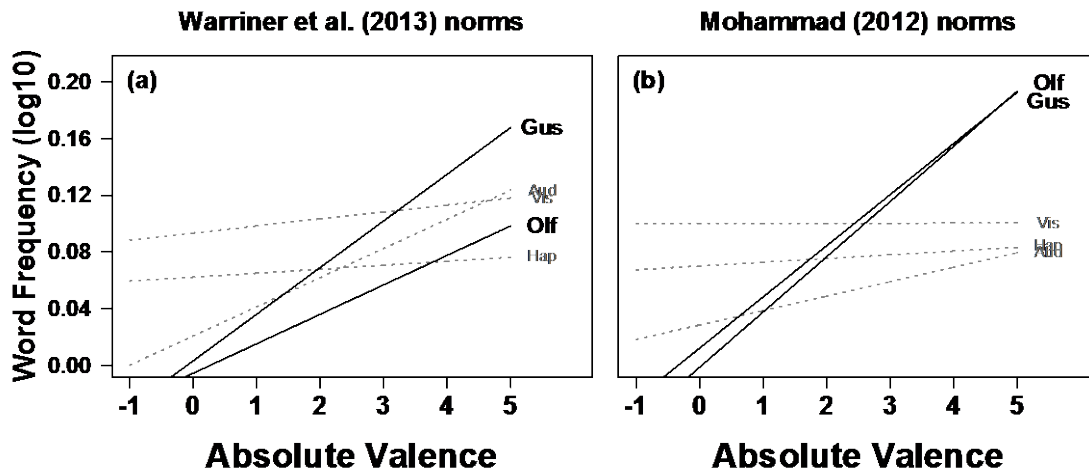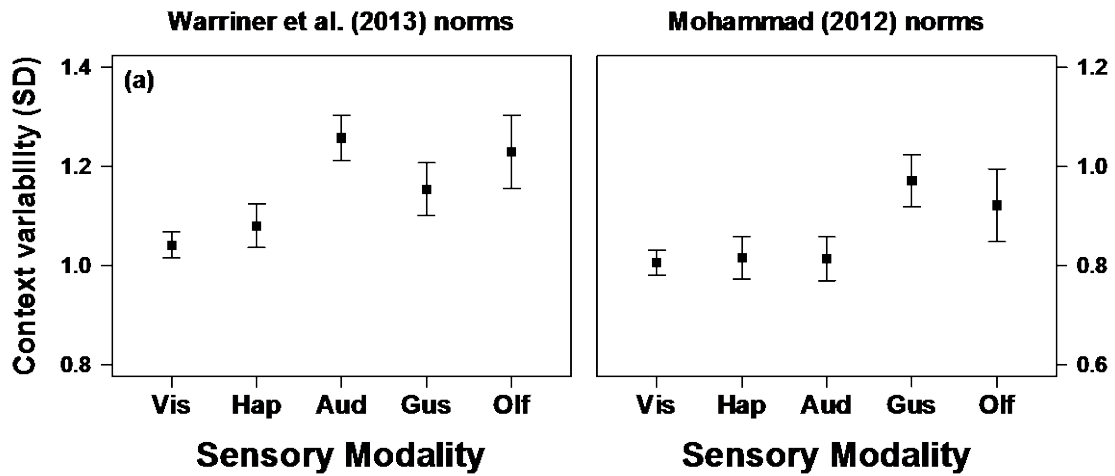

Figure 2: Linear model fits and 95% confidence intervals for (a) context valence and (b) absolute context valence for the Warriner et al. (2013) dataset

Figure 3: Linear mixed effects model fits showing the relationship between frequency and absolute valence for all five modalities, for (a) the Warriner et al. (2013) norms and (b) the Mohammad (2012) norms

Figure 4: Linear model fits and 95% confidence intervals for context variability from (a) the Warriner et al. (2013) dataset and (b) the Mohammad (2012) dataset