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The Emotion Code in Sensory Modalities: An investigation of the relationship between sensorimotor dimensions and emotional valence-arousal

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Abstract. Human sensations and emotions are our primary embodied feelings in experiencing the outside world. The two systems are closely intertwined and jointly contribute to cognitive processes such as lan- guage use. However, how the two systems interact as manifested in our languages is still not well understood. This paper utilizes perceptual strengths and affective ratings to delve into the interaction between spe- cific sensory modalities and emotional valence-arousal in Chinese. We found that smell and interoception, considered the two sensations di- rectly linked to emotional processing, are more emotional and can elicit higher arousal levels than words associated with other senses. This study demonstrates the relevance and significance of the relationship between sensorimotor and affective information. It further sheds light on the em- bodied effect and associated emotional implications in the Chinese lan- guage.

Keywords: sensorimotor norms · sensory modalities · valence · arousal · emotion

1 Introduction

Embodied cognition theories posit embodied experiences are encoded in the knowledge system and will be reactivated via cortical network simulation mechanisms in response to the original stimulus and/or its related stimuli (cf. [1–3]). For example, comprehending the word *cat* automatically simulates the senso- rimotor, affection, and/or mental state that is associated with one's previous encounters with an actual cat, which includes but is not limited to what a cat looks like (via visual perception), what a cat sounds like (via auditory percep- tion), what a cat feels like (via tactile perception), and what one's mental feeling is about a cat (e.g., via emotions). In general, our bodily physical interactions with the outside world ground cognitive processing and further influence our conceptual knowledge system.

To explore the fundamental position of the sensorimotor system in one of the most important cognitive processes, i.e., language comprehension, a proliferation

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of behavioral and neurological studies has tapped into the effects of sensorimo- tor and affective information on semantic processing (e.g., [4–6]). Recently, using the perceptual and action strengths assigned to lexical items, a series of percep- tual strength norming studies (also known as modality exclusivity norms, or sensorimotor norms) has unraveled that specific sensory modalities (e.g., vision, hearing, smell, taste) and/or action effectors (e.g., head, mouth, leg, arm) weight differently in different concepts across a variety of languages (see, e.g., [7–9]). Importantly, a sensation denoting internal bodily states, *interoception*, shares overlapping processing mechanisms with emotional experiences [10, 11] and is thus suggested as a 'scaffolding' sense that associates physical sensations with mental representation as well as grounds abstract concepts [12, 13].[3]

With regard to affective experiences, they were usually operationalized through a two-dimensional valence-arousal space (see Fig.1 below). The dimension of valence denotes how positive or negative a concept is, whereas the dimension of arousal represents whether a concept is excited/tense (high-arousal) or calm/tired (low-arousal) (cf.[14]). Emotional valence or affective norms were normally collected for valence and arousal ratings in psychological studies (e.g., [15–17]). These studies focused mainly on correlations between valence and arousal val- ues, with valence being recognized as the most powerful measure of the emotional nature of stimuli.

However, despite the considerable evidence of recruiting sensorimotor mechanisms in language comprehension that has been posed, the interaction between sensorimotor and affective systems coded in the semantic processing is still an underexplored topic. A direct linguistic attestation between specific sensory modalities and emotional valence is examined in [19], in which English gustatory- and olfactory-related lexical items were found to be more 'valenced' or 'emotion-laden' than words associated with other sensory modalities. Such emotional preference over gustatory and olfactory senses might be attributed to the neural base of the odors and flavors—they activate specific brain regions for emotional processing [20]. Winter [19] additionally proposed that olfaction contains more unpleasant and negative concepts than gustatory sense (for a similar idea, see [21]). Interestingly, the etymologies of the two adjectives in English describing a preferable flavor and an unpleasant odor, i.e., *tasty* and *smelly*, are originated in *to taste/taste* and *to smell/smell*, which denote an action of perceiving (or the perception of) a flavor and an action of perceiving (or the perception of) an odor, respectively.

Even though sensorimotor and emotional mechanisms are supposedly shared universally regardless of which language one speaks, social and cultural experiences might lexicalize inner bodily feelings, especially those related to emotions, distinctively across languages. This paper, thus, takes Chinese as a case in point to explore the reciprocal interaction of specific sensorimotor dimensions with emotional valence. More specifically, we will adopt the ratings collected in a

[3] Note that the five traditional sensory modalities, i.e., visual, auditory, gustatory, olfactory, and tactile senses, mainly detect signals from the external stimuli rather than from the inner body.

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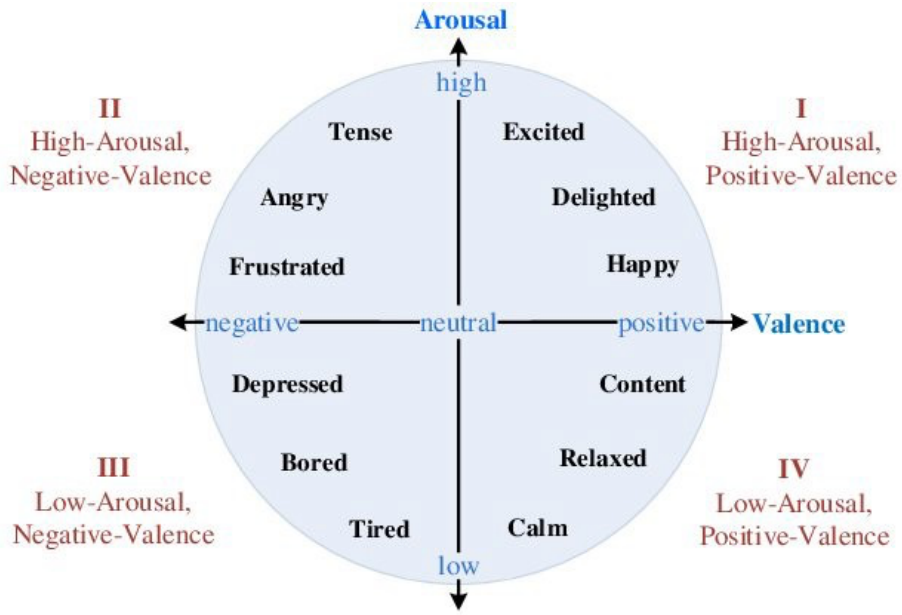

Fig. 1. Two-dimensional-valence-arousal space ([18], p.541)

study of sensorimotor norms of Chinese nouns [9] and another study of affective ratings in simplified Chinese words [17] to look for possible convergence between these two distinct yet affiliated systems. We ask two main research questions in this paper:

RQ1: Will sensory modalities influence affection (valence-arousal degree) in the Chinese language?

RQ2: Will affection (valence-arousal degree) differs in sensory modal- ities in the Chinese language?

2 Method

2.1 Dataset 1: Sensorimotor Norms

The dataset concerning sensorimotor strength was collected for 664 disyllabic Chinese nouns among native speakers of Mandarin Chinese [9]. This study asked participants to rate how much they experience each concept based on their six perceptual senses (i.e., vision, hearing, taste, smell, touch, and interoception) and the five action effectors from different parts of the body (i.e., foot/leg, hand/arm, head excluding mouth, mouth/throat, and torso), from 0 = no feelings at all, to 5
= very strong feelings. In order to identify which sensorimotor dimension is most

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associated with a word, "dominant sensory modality" as well as "dominant ac- tion effector" were assigned to each word according to the maximum perceptual and action strength across the six senses and the five effectors. Since previous studies only discussed emotional valence in the context of sensory modalities (e.g., [19, 21]), we will also only consider dominant sensory modalities in this study.[4] Zhong et al. [9] found that among the six sensory modalities, intero- ception is the dominant sense (n = 289; 43.5%), followed by visual (n = 211; 31.8%), auditory (n = 122; 18.4%), gustatory (n = 19; 2.9%), and olfactory and tactile (n = 8; 1.2%). Four words had their dominance in visual and interoception (n = 4; 0.6%), and three words shared the dominant modality in gustatory and olfactory (n = 3; 0.5%). In this paper, the seven words sharing the common dom- inant sensory modalities will be excluded because the dominant dimension will be exclusive for the current purpose. Therefore, the sensorimotor norms dataset consists of the perceptual strength of the 657 disyllabic Chinese nouns in all the six sensory modalities, and each word will have its sole dominant sensory modality.

2.2 Dataset 2: Affective Ratings

The second dataset is from a large-scale affective ratings study collected among 11,310 simplified Chinese words, including 9774 two-character words, 949 three-character words, and 587 four-character words [17]. Following the convention in previous affective norming studies, Xu et al. [17] asked participants to rate on a 7-point scale for valence ratings, ranging from -3 = extremely negative, 0 = neutral, to +3 = extremely positive. For the arousal ratings, participants were asked to rate on a 5-point scale, 0 = very low arousal to 4 = very high arousal. To incorporate the sensorimotor norms into the affective ratings, we mapped the words in Dataset 1 to Dataset 2 and identified 649 two-character nouns as the data in this study.[5]

2.3 Data Analysis

We follow the "absolute valence" measurement in Winter [19] to calculate ab- solute valence values in addition to the valence ratings for the lexical items. Absolute valence removes the negative sign and entails whether a concept is "emotion-laden" irrespective of the actual valence value it receives.[6]

A simple linear model is fitted, with **valence**, **absolute valence**, and **arousal** analyzed separately as dependent variables. **Dominant sensory modality** (i.e.,

[4] Another reason for omitting dominant action effectors is because almost all the action effectors jointly shared a dominant place with other effectors in [9] since action strength is relatively low for noun concepts. Therefore, considering the statistical power, we will mainly focus on sensory modalities in this paper.

[5] Note the words in the two datasets were both from a Mega study of Lexical Decision in Simplified Chinese (MELD-SCH, Tsang et al.[22]).

[6] Absolute valence is achieved by subtracting the mean of all valence ratings from each rating and then taking the absolute value.

vision, hearing, touch, taste, smell, and interoception) is considered the categorical predictor. All the analyses were conducted with JASP [23].[7]

3 Results

3.1 Valence and Absolute Valence

Table 1 shows the average (Mean), standard error (SE), and standard deviation (SD) of the valence and absolute valence across six dominant sensory modalities. On average, gustatory words had the highest valence score (M = 0.56, SD = 0.40), while olfactory words received the lowest rating (M = 0.12, SD = 1.36). However, the linear model for valence ratings was not well fitted (adjusted R^2 = -.003). Moreover, no effect of dominant sensory modality was suggested for the valence ratings, $F(5, 643) = 0.67$, $p = .646$.

Table 1. Mean, SE, and SD of the valence and absolute valence across dominant modalities.

	Dominant Modality	N	Mean	SE	SD
Valence	Auditory	122	0.283	0.0581	0.642
	Gustatory	19	0.555	0.0917	0.400
	Interoceptive	284	0.377	0.0593	0.999
	Olfactory	8	0.116	0.4824	1.364
	Tactile	8	0.226	0.0967	0.273
	Visual	208	0.334	0.0398	0.575
Absolute Valence	Auditory	122	0.445	0.0421	0.465
	Gustatory	19	0.254	0.0852	0.371
	Interoceptive	284	0.767	0.0379	0.639
	Olfactory	8	1.166	0.2142	0.606
	Tactile	8	0.237	0.0582	0.165
	Visual	208	0.366	0.0307	0.442

Considering the absolute valence, olfactory lexical items were the most "emo- tion laden" (M = 1.17, SD = 0.61), and the second highly emotional modal- ity was interoception (M = 0.77, SD = 0.64). Tactile sense was seen the least emotion-laden modality among the six sensory modalities (M = 0.24, SD = 0.17). The model for the absolute valence fits, accounting for 12% of the variance in absolute valence ratings (adjusted R^2 = .12). There was a significant effect of dominant modality on the absolute valence ratings ($F(5, 643) = 18.62$, p <.001). A post hoc comparison showed that interoceptive words were more emotional than auditory (t (643) = 5.51, p <.001), gustatory (t (643) = 4.00, p = .001), and visual (t (643) = 8.13, p = .001) items. Olfactory words were also found more valenced than auditory (t (643) = 3.66, p = .004), gustatory (t (643) = 4.01, p = .001), and visual (t (643) = 4.11, p = <.001) words.

[7]JASP is a free and open-source program for statistical analysis.

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3.2 Arousal

Applying the same method as the valence and absolute valence, we provide the average (Mean), standard error (SE), and standard deviation (SD) of the arousal ratings across six dominant sensory modalities in Table 2.

Table 2. Mean, SE, and SD of the arousal across dominant modalities.

	Dominant Modality	N	Mean	SE	SD
Arousal	Auditory	122	2.02	0.0381	0.421
	Gustatory	19	2.06	0.1116	0.487
	Interoceptive	284	2.14	0.0284	0.479
	Olfactory	8	2.42	0.1178	0.333
	Tactile	8	1.75	0.0964	0.273
	Visual	208	1.93	0.0300	0.433

The overall results for arousal ratings replicated those for absolute valence, in which olfactory items were considered the highest arousal (M = 2.42, SD = 0.33), and the second-highest arousal modality was interoception (M = 2.14, SD = 0.48). Touch was seen as the lowest arousal sense (M = 1.75, SD = 0.27). In general, the model for the arousal fits, with 5% of the variance in arousal ratings (adjusted R^2 = .05). A significant effect of modality was likewise suggested on the arousal ratings (F (5, 643) = 7.15, p <.001). A post hoc comparison showed that interoceptive words had higher arousal than visual items (t (643) = 5.15, p <.001), and olfactory words also had higher arousal than visual words (t (643) = 3.01, p = .041).

4 Discussion & Conclusion

Consolidating Chinese sensorimotor norms and affective ratings, this paper explores how sensory modalities interact with emotional experiences—valence and arousal, in particular. First, we found evidence suggesting that dominant sensory modalities may affect the valence and arousal degree in the Chinese language, especially on absolute valence and arousal values. The reason for the null effect of dominant sensory modalities on valence might because the degree of valence has been "neutralized." Significant effect of dominant sensory modalities was suggested on absolute valence; that means, some sensory modalities are more "emotion laden" than others. Significant effect of dominant sensory modalities was likewise suggested on arousal – some sensory modalities are more "aroused" than others.

Concerning the second question on the differentiation of affection in the sensory modalities, our findings suggested that gustatory nouns elicited the most positive affection while olfactory words were the most negative. Other modal- ities are in between the two extremes. However, when positive or negative va- lence is discarded, interoception and olfaction are the two prominent "emotional"

modalities that are more "emotion laden" than auditory, gustatory, and visual senses. Arousal replicated the result for the absolute valence, in which interoceptive and olfactory lexical items evoked higher arousal levels than visual words. Some samples words that are dominant in olfactory and interoceptive senses are demonstrated in Figure 2 and 3, respectively.

Fig. 2. Sample words with olfaction as their dominant sense

The findings mostly coincide with Winter's [19] study of affective loadings in the English lexicon. When considering actual valence values, gustatory words are the most positive while olfactory vocabulary is the most negative. For the case of Chinese, this is mainly because the nouns dominated by taste are mostly related to food items (e.g., 水果 *shui3guo3* 'fruit' and 蛋糕 *dan4gao1* 'cake'), which may largely elicit people's positive memories and experiences of the tastes and flavors of these foods, whereas the valence ratings for smell were possibly pulled low by two words that explicitly connote bad taste, i.e., 臭味 *chou4wei4* 'foul smell' and 腥臭 *xing1chou4* 'stinking smell.' Nevertheless, the model and the results were not capable of differentiating emotional valence across different sensory modalities.

However, the consistent findings of absolute valence and arousal suggest that smell and interoception are the two senses that are 'closest' to our affection. Note that the absolute valence only considers if a sensory modalities is emo- tional valenced regardless of the emotional strength. This finding is in line with neurological evidence because olfactory and interoceptive senses are directly connected with the emotional mechanism in our neural systems. There is evidence

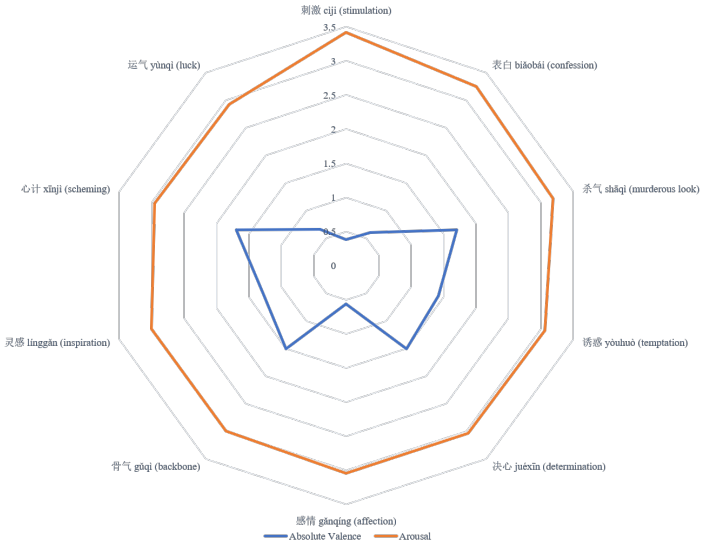

Fig. 3. Sample words with interoception as their dominant sense

that different odors can elicit pleasant or unpleasant responses, influence cognition and emotion, and modulate psychological and physiological states [24]. The affective system also shares the same mechanism with interoception [25, 26]. Emotions are often accompanied by bodily changes; for example, our heart beat faster when we feel embarrassed, and our breath go shallow when we are in fear. Further, sensing these autonomic changes is processed within our body, which is detected by the interoceptive sensation. Such intimate relatedness of the physiological and mental states possibly ground our cognitive processes and is further reflected in language representations. For example, those lexical items dominated by interoceptive sense mostly depict emotionally abstract concepts such as 胸怀 *xiong1huai2* 'heart; mind,' 苦海 *ku3hai3* 'abyss of misery,' and悲叹 *bei1tan4* 'sigh mournfully' (for a discussion of the relationship between interoception and abstractness via the sensorimotor strength, see [13]).

It is worth noting that the present study may only reflect how emotional values are encoded in one type of part-of-speech, i.e., nouns; and the volume of dominant sensory modalities is considerably scarce for certain senses—for exam- ple, olfactory and tactile senses (only eight words are dominated by smell and/or touch). Another limitation is that we did not consider the context that the sensory lexicon appears. Provided that adjectives and contextual information (e.g., semantic prosody) predict emotional differences among sensory modalities [19], the association between these factors needs to be investigated in future studies.

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