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The Use of Semantic Differential Scaling to Define the Multi-Dimensional Representation of Odors

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Abstract

The mental representation elicited by smelling an odor often consists of multiple sensory and affective dimensions, yet, the richness of this elaboration is difficult to capture using methods to rate the intensity of these factors in isolation. Attempts to use language descriptors for olfactory experience have also been shown to be rather limited; among non-specialists, there is no universally accepted system for describing odors, leading to greater reliance on specific item associations. In this study we explored the utility of semantic differential scaling for illustrating the various dimensions of olfactory experience. 300 volunteers rated thirty distinct odorants using 50 SDS adjectives. Three factors emerged from the analysis (based on 17 adjective-pairs) accounting for 53% of the variance, and corresponding to the evaluation, potency and activity dimensions identified for other stimulus types. SD scaling appears to be a viable method for identifying the multiple dimensions of mental representation evoked when smelling an odorant and may prove a useful tool for both consumer and basic research alike.

Practical Applications—Although numerous methods of classifying odors have been developed, little agreement has been achieved on the dimensions that are useful to both basic and consumer research. The identification of a set of Semantic Differential adjectives which are relevant to olfactory experience can become a useful tool for classifying the qualitative and affective basis on which odorants differ.. In particular, the degree to which odorants evokes multi-dimensional representations from other sensory modalities (visual, auditory, somatosensory or gustatory), can be usefully applied in the arena of product development both within and across cultures.

Keywords

Semantic differential scaling; sensory evaluation; olfaction; fragrance perception; emotion

Introduction

It is well established that in everyday life, there is a strong affective component to our olfactory experience. Indeed, when smelling a novel odor for the first time our initial reaction is to determine whether we like or dislike the odor. Subsequent exposure to even a familiar odor often evokes an emotional response (good-bad) prior to any other conscious awareness of the odor properties or source. Indeed, Woskow (Woskow, 1968), using multi-dimensional mapping techniques, identified one of the primary dimensions of olfactory experience as an affective one. Not surprisingly, considerable research has suggested that olfactory representations can be potent, although perhaps not unique, triggers of emotional

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experience (Herz, 1998; Herz and Engen, 1996; Vernet-Maury *et al.*, 1999). However, capturing the qualitative and affective dimensions of an odorant representation for any given individual has proven to be somewhat elusive. Most scales are uni-dimensional and may not illuminate the complexity of the emotions or other qualities associated with the odorant representation.

The use of language to explore this olfactory-affective experience also has its limitations. When smelling an odor, it is common to recognize that it is familiar and that it belongs in a general class or category (i.e. food vs. floral), but producing a name or label for the olfactory sensation is often a very difficult task. Several factors have been proposed to account for this phenomenon, commonly called 'the tip of the nose' (Lawless and Engen, 1977). For one thing, encoding of any odor sensation is frequently done in association with a situation, location, person or emotional context rather than a lexical one, so the label is often not the primary association immediately available. In addition, there is no universally accepted system for describing many odors which also leads to greater reliance on specific item associations. However, although the descriptive vocabulary for smells is sparse and limited primarily to nomenclature related to the source objects (i.e., smells like orange, banana, coffee) or the situation where encountered (i.e., smells like the movies, beach, locker room), the mental representation of any odor may well consist of a rich network of semantic dimensions which can be elucidated via language. The English language used to describe an odorant is multi-dimensional and comprised of auditory, visual, taste, and tactile components. For example, an odorant can be described as soft (auditory and tactile), sweet (taste), or floral (olfactory and visual). That our experience of an odorant involves more than mere olfactory perception has also been demonstrated by the ease in which people can match the intensity of an odorant to the pitch of a sound or to the hue and saturation of a color (Kemp and Gilbert, 1997; Gilbert *et al.*, 1996).

Most attempts to chart an individual's qualitative judgment and affective response to an odorant have relied on characterizations of odor quality via intensity scaling with lists of odor quality descriptors (Lawless, 1989), measures of mood or autonomic state while smelling an odorant (Ehrlichman *et al.*, 1995; Ehrlichman and Halpern, 1988). The classic treatise for odor classification attempted to establish a common lexicon for qualitative description of odors (Harper *et al*, 1968). Yet, four decades later there is still no generally accepted system of classification that encompasses the olfactory world, limiting not only communication among individuals involved in sensory evaluation, but also impeding a basic understanding of the cognitive processes involved in discrimination of odor quality (Lawless, 1988). Moreover, going beyond purely descriptive olfactory property, the richness of semantic elaboration that can be connotative of emotion has largely been ignored in studies of olfaction. Tapping into the multi-sensory semantic representation that is elicited by smelling an odor could be of great utility in a number of applications where simple olfactory descriptors provide a barrier to a full understanding of the sensory and emotional experience elicited by an odor. Lawless (Lawless, 1999) has persuasively argued that that assumptions of independence in odor quality descriptors in the psychophysical intensity model may be insufficient to fully capture the multi-dimensional nature of odor representation. In addition, developing a classification system to obviate utilizing culture-specific odor quality descriptors can foster better cross-cultural comparisons of olfactory experience. For these reasons, we explored whether Semantic Differential Scaling, a well-established method for evaluating affective responses to examples in many other stimulus domains, would be of utility in characterizing the affective response to odors.

The Semantic Differential Technique

The Semantic Differential (SD) technique was originally developed to measure people's affective responses to stimulus words and concepts in terms of ratings of bipolar scales defined with adjectives on each end (Osgood, 1962; Osgood, 1957). The SD methodology was considered a simple, economical means for obtaining data on emotional reactions that could be used in many different situations or cultural contexts.

Numerous studies using the SD technique to map the mental representation of words, line drawings, and concepts have demonstrated that three basic dimensions of variation, evaluation, potency and activity (EPA), account for most of the co-variation in ratings. Some adjective scales are nearly pure measures of an EPA dimension (good-bad for evaluation, strong-weak for potency, fast-slow for activity) while others may be more oblique in representing a dimension (light-dark for either evaluation or potency).

Although the SD technique was in wide use after its origination, only one study using this technique to evaluate odor experience was published. This study was an attempt to compare traditional multi-dimensional scaling techniques with the SD technique among a native Japanese population using a set of familiar odorants (Yoshida, 1964). Following factor analysis of both methods, the SD technique appeared to yield three factors (as compared to six for the MDS technique), which were labeled as (1) sensory pleasure, (2) harshness, and (3) intensity or vividness. Despite the small sample size and stimulus set utilized, that the SD technique yielded the same basic 3-factor dimensions for odors as it did for stimuli in other modalities, suggests that the SD technique may be useful in this application.

The goal of the current study was to use the SD methodology to determine the dimensions of affective variation inherent in olfactory experience and representation, and more practically to develop from a larger group, a set of SD adjectives which were most relevant and useful for evaluating olfactory experience. In line with the argument advanced by Lawless (Lawless, 1999), utilizing a method which employs ratings of similarity to various semantic concepts we neither implied nor assumed independence or separability of these attributes, but rather attempted to capture the multidimensional space that these odor representations occupy.

Materials and Methods

Participants

300 healthy adults were tested. They had a mean age of 28 (+/−11) and were approximately equally distributed between males (n=149) and females (n=151). They were drawn from the metropolitan Philadelphia area and recruited through advertisements placed in local newspapers. The racial/ethnic distribution of the test population was as follows: Caucasian (n=145), African-American (n=47), Asians (n=87), Hispanic (n=16) and Native American (n=5). The individuals who were selected were free of colds or allergies at the time they were being tested. All participants completed standardized vocabulary tests prior to enrollment in the study to ensure minimum comparable verbal skills.

Odor Stimuli

Table 1 presents the 30 odorants that were used in this study. The odorants were delivered in the form of Viscopearls ™, small polystyrene beads that were impregnated with the appropriate fragrance, obtained from the KAO company (KAO, Tokyo, Japan) and matched for relative intensity. 2.0 g of the fragrance beads were placed into small, opaque jars that were covered with a perforated plastic cover, through which the subjects could sniff the fragrance. An airtight cover was placed on the jars when the odorants were not being

sampled and were refrigerated when not being used at 45 F to maintain consistency over the course of the study.

Since rating 30 odorants on 50 scales is an extremely time-consuming task and in particular, in the field of olfaction, can adapt or desensitize the nose, the odorants were divided into 3 sets and each set was rated by a group of 100 subjects. Each subject evaluated only 10 odor stimuli out of the 30 total using the semantic differential scale, but the assignment of odorant stimuli to subjects was randomized so that 100 subjects evaluated each odorant. The odorants were selected to represent odors that were both familiar (i.e., lemon, banana) and unfamiliar (i.e., hinoki, galbanum, cassis) to participants in the US. Each set of 10 contained both familiar and unfamiliar odorants.

Experimental Measures

Standardized Vocabulary Test

A 20-item vocabulary test, with items chosen to be at the 8th grade level, was administered to each subject in order to obtain a measure of verbal comprehension and linguistic ability. This verbal score measure was used to screen individuals prior to recruiting them for participation in the study, with a passing score of 95% required. A passing rate of >96% on this measure only required that 312 individuals be screened in order to obtain 300 participants (100 in each group).

Semantic differential scale

Each odorant was evaluated using a semantic differential scale (SDS). The SDS consisted of 50 pairs of polar adjectives used to describe different sensory experiences (e.g., bright vs. dark, happy vs. sad, slow vs. fast, hard vs. soft) (see Table 2). Based on previous research on non-olfactory stimuli (Osgood, 1962), the adjectives were drawn from 3 general dimensions: evaluation (e.g., pleasant – unpleasant), potency (e.g., strong – weak, hard – soft), and activity (e.g., active – passive, sharp – dull). Each adjective pair was rated on a 7-point scale.

Although the SDS was initially developed as a method to dissect the meaning of concepts or attitudes, it could be easily adapted to differentiate the meanings of various odorants. A principal component analysis (PCA) was used to determine the components and dimensions used to describe various odorants. PCA and perceptual mapping was also used to generate olfactory space along different dimensions.

For example,

(odor A)

Polar Term X____:____:____:____:____:____:____:Polar Term Y
(1) (2) (3) (4) (5) (6) (7)

(1) extremely X

(2) quite X

(3) slightly X

(4) neither X nor Y; equally X and Y

(5) slightly Y

(6) quite Y

(7) extremely Y

Procedure—During the session (1.5 hours) the subjects were asked to rate each of 10 odorants (either Set A, B or C) using the semantic differential adjectives shown in Table 2. They were also asked to indicate how familiar each odor was (using a category scale) and, if they had smelled it before, to indicate the approximate age at which this first occurred, using a category scale (0-5 years old; 5-10; 10-15; 15-25; 25 or >). All ratings were made on a computer. The order of presentation was fixed within each set, but the presentation was self-paced. Subjects were told to uncap the jar and sniff from the contents while they made their ratings; they were encouraged to re-sniff the odors while rating it using each of the 50 adjectives.

Results

As we anticipated, not all of the SD adjective pairs selected and tested would be equally relevant to evaluating olfactory stimuli. Thus, one goal of the study was to identify, from the 50 semantic pairs, which were most discriminative among the various odorants, using analysis of variance. Following this, we performed a principal component analysis on the relevant scales to determine factor scores for each of the odorants which would provide a metric for classifying them along semantic dimensions in perceptual space.

Data Analysis

Principal component analysis was carried out using Statistica 6.1 ™ with varimax rotation on the SD adjective pairs in order to extract the number of factors present in the data and to identify which descriptors loaded most highly on each factor. Consistent with SD research on other stimulus types, three dimensions or factors emerged from the analysis. The first factor accounted for 32% of the variance, the second for 15% of the variance and the third for 5.9% of the variance for a total of 53%. No other factors emerged to explain significant variance from the analysis. Table 3 depicts the SD adjectives with loadings greater than +/−. 70 on each of the three factors. Importantly, we found that with the exception of two adjectives, each of these adjective pairs were relatively pure measures of the dimensions such that each had a high loading on only one factor or dimension.

Moreover, an examination of the adjective pairs loading on each dimension suggested a close correspondence with the evaluation, potency and activity (EPA) dimensions identified in prior research: Factor 1 appeared to correspond to the evaluative dimension, factor 2 appeared to represent potency, while factor 3 connoted activity.

Having determined which scales were most relevant to evaluating the semantic properties of odorants, the ratings on these 17 scales were converted into factor scores by assigning numerical values to the scale positions (−3 to +3 for the 7 scale positions) and obtaining the mean value for each odorant. Given that the factor loadings for the scales were all in excess of +/−.70 and that the scales loaded mainly on one dimension, the scales were weighted equally when calculating the factor scores for each odorant. For clarity in exposition, Figures 1-3 depict the mean factor scores for each dimension for the three sets of odorants separately. As can be seen in each figure, the odorants appear to be well separated in dimensional space by this method. For example, odorants which were judged to be highly unfamiliar to the US population tested (i.e. hinoki, galbanum, leafy green) occupied the3-dimensional space connoting negative, potent and highly active odorants. In contrast, odorants which were highly familiar to this group (i.e., vanilla, apple, coconut) tended to occupy the 3- dimensional space connoting positive, weak and inactive odorants. Familiar

odorants that also elicited sensations such as tingling, burning or cooling (i.e., peppermint, cinnamon) were rated as more intense and more active than familiar odorants which lacked those properties.

Discussion

The use of the semantic differential technique to explore responses to odorant qualities appears to be a simple way to evaluate the semantic and affective dimensions which underlie the mental representation of an odorant. Results available from the use of this technique go beyond those obtained from classical discriminations of odorants or intensity ratings of quality. While these standard techniques are useful ways to characterize qualitative or even affective intensity differences among odorants, they presume a certain level of orthogonality between dimensions and thus do not provide information on the multidimensional qualitative and affective variation for unitary odor percepts, an outcome of increasing interest among both industry and basic researchers.

The utility of the SD technique in cross-cultural studies has been consistently validated for other types of stimuli (Osgood, 1964; 1965). From a practical perspective, a set of semantic scales which may be relevant to assessing odorant responses among a US population could and should be tested on another population in order to determine their applicability for obtaining cross-cultural comparisons on affective responses to odors.

Obviously, other components of olfactory experience, such as familiarity or memorability, may well be related to one or more of the EPA dimensions and can easily be incorporated into a study wherein SD scaling and other constructs are measured. Thus, the ability to quantify the various dimensions of quality and emotions evoked when smelling an odorant may prove a useful adjunct to both consumer and basic research alike.

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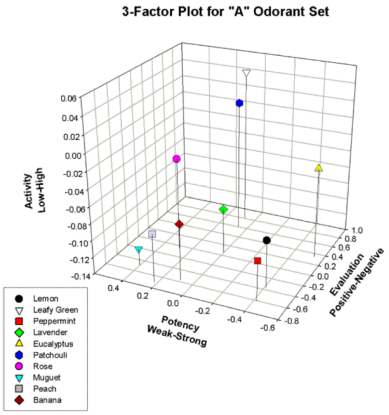

Figure 1.
Three-factor plot of odorants in Set A, illustrating the variation among odorants on the three dimensions extracted from the semantic differential scaling.

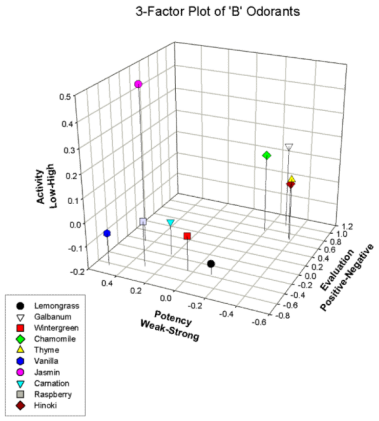

Figure 2.
Three-factor plot of odorants in Set B.

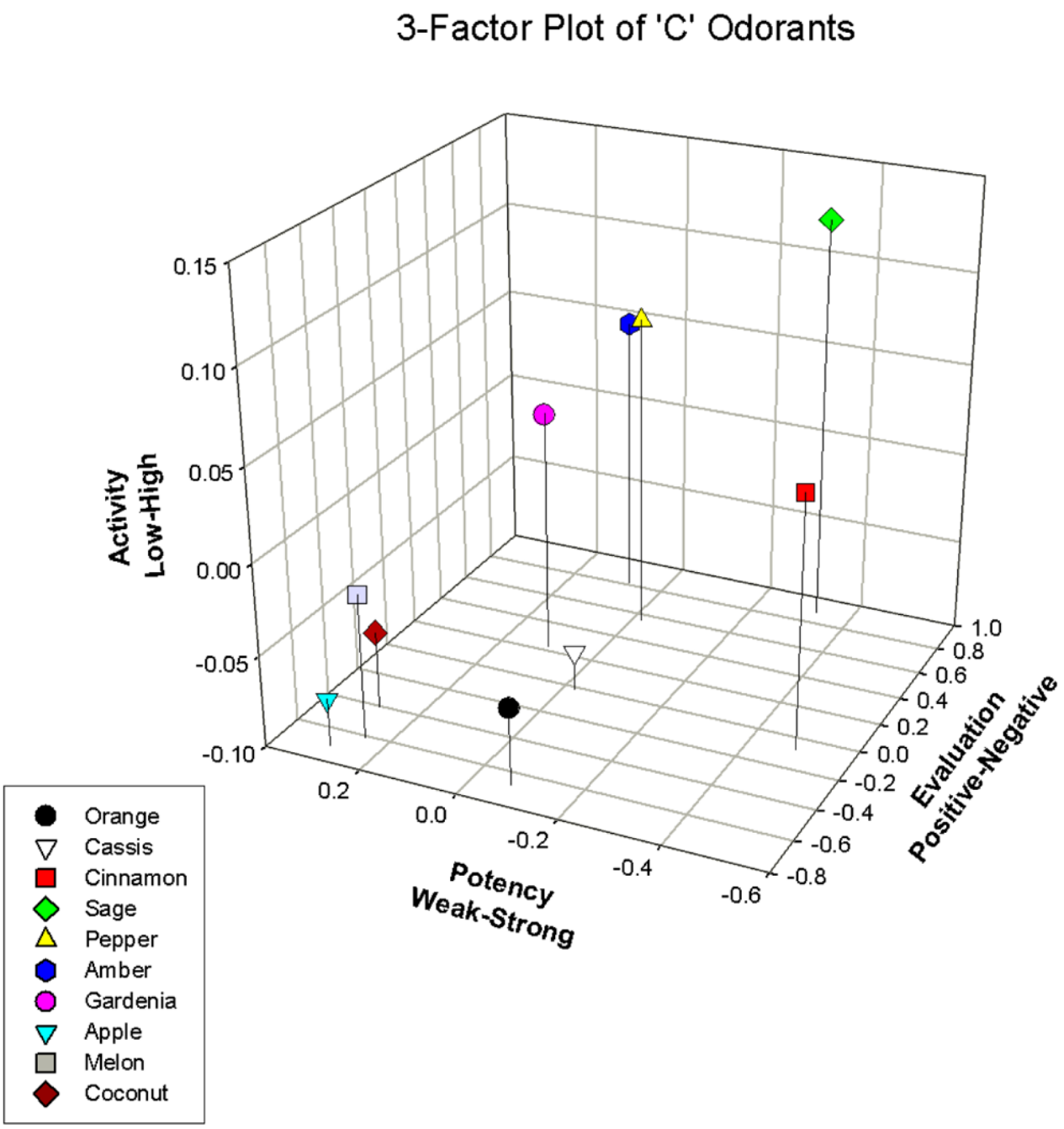

Figure 3.
Three-factor plot of odorants in Set C.

Table 1

Sets of odorant stimuli

	A		**B**		**C**
A1	Lemon	B1	Lemongrass	C1	Orange
A2	Leafy green	B2	Galbanum	C2	Cassis
A3	Peppermint	B3	Wintergreen	C3	Cinnamon
A4	Lavender	B4	Chamomile	C4	Sage
A5	Eucalyptus	B5	Thyme	C5	Pepper
A6	Patchouli	B6	Vanilla	C6	Amber
A7	Rose	B7	Jasmine	C7	Gardenia
A8	Muguet	B8	Carnation	C8	Apple
A9	Peach	B9	Raspberry	C9	Melon
A10	Banana	B10	Hinoki	C10	Coconut

Table 2

Semantic Differential Adjectives Used to Evaluate Odorants

1.	stable	-	unstable
2.	hard	-	soft
3.	excitable	-	calm
4.	happy	-	sad
5.	hot	-	cold
6.	deep	-	shallow
7.	heavy	-	light
8.	strong	-	weak
9.	full	-	empty
10.	wet	-	dry
11.	light	-	dark
12.	new	-	old
13.	distinct	-	vague
14.	sharp	-	blunt
15.	healthy	-	unhealthy
16.	tense	-	relaxed
17.	smooth	-	rough
18.	beautiful	-	ugly
19.	intellectual	-	unintellectual
20.	good	-	bad
21.	ordered	-	chaotic
22.	unreal	-	real
23.	dynamic	-	static
24.	fresh	-	stale
25.	dangerous	-	safe
26.	clear	-	muddy
27.	jubilant	-	sober
28.	rounded	-	angular
29.	characteristic	-	common
30.	interesting	-	boring
31.	positive	-	negative
32.	masculine	-	feminine
33.	clean	-	dirty
34.	sour	-	sweet
35.	passive	-	active
36.	simple	-	complex
37.	relaxing	-	stimulating
38.	natural	-	chemical
39.	aromatic	-	medicinal
40.	bitter	-	sweet

41.	plain	-	fancy
42.	mild	-	harsh
43.	sturdy	-	fragile
44.	alive	-	dead
45.	powerful	-	powerless
46.	quiet	-	noisy
47.	harmonious	-	unharmonious
48.	plain	-	colorful
49.	burning	-	freezing
50.	spicy	-	bland

Table 3

Adjective loadings on each dimensions

Factor 1 (Evaluation)	**Factor 2 (Potency)**	**Factor 3 (Activity)**
Fresh-stale	Strong-Weak	Ordered-Chaotic
Good –Bad	Powerful-Powerless	Quiet-Noisy
Happy-Sad	Harsh-Mild	Relaxing-Stimulating
Harmonious-Unharmonious		Wet-Dry
Healthy-Unhealthy		Muddy-Clear
Beautiful-Ugly		
Smooth-Rough		
Clean-Dirty		
Safe-Dangerous		