On Dimensions in Emotion Psychology

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Abstract— **Is the study of the dimensional space that is meant to represent human emotions helpful in understanding the mechanisms underlying emotional processes? Emotional experience is frequently described along a certain number of dimensions, often including valence and arousal. This paper argues that dimensional models may obfuscate the mechanisms underlying the genesis of emotions. A parallel is drawn to dimensions of gustatory experience. Data are presented on the dimensional representation of taste, and compared with information about peripheral processing of basic tastes. While the obvious discrepancies might inspire more fascinating search for the next stage of gustatory processing, too little is known on basic emotional processing, in order to profit from a similar comparison.**

Emotional space; dimensions; valence; arousal; sweet; sour

I. Introduction

The cognitive space representing human emotions is often described along a certain number of dimensions. Wilhelm Wundt [1] postulated three dimensions of emotional experience, namely Lust (pleasure or valence), Erregung (activation or arousal) and Spannung (strain or tension). Among emotion researchers, the first two of these dimensions (valence and arousal) are in wide use. Several authors see the need for a third dimension to describe emotional experience. The most common names for the third dimension, in today's emotion models, are potency [2], and dominance [3]. Reference [4] argues that a fourth dimension is needed, and refers to it as unpredictability.

The present paper argues that a dimensional analysis of the cognitive representation of emotions is not helpful when trying to understand the underpinnings of emotions. This is demonstrated by applying a dimensional approach to gustatory data. The question is what we would learn from this analysis if we knew as little about taste as we know about emotions. While some of the problems of dimensional analysis discussed in this paper might generalize to other domains of cognitive or perception science, it is especially the difference in knowledge in these two domains that inspired the comparison. It is argued that without a profound previous knowledge in the domain under study, dimensional analysis of its cognitive representation might mislead more than illuminate.

II. Exploring the Taste Space

Much is known about the basic qualities of taste and their respective receptors [5] (for a recent discussion see [6]). We know of five basic qualities, namely sweet, sour, salty, bitter, and umami ('meaty', glutamate receptor). A sixth basic quality (fatty) is under dispute [7].

Now let us, for the moment, forget everything we know about the psychophysiological mechanisms underlying taste perception. If we propound that in order to understand taste perception, we need to determine a taste space, we should endeavor to ascertain the best method to asses the nature of this space. Rating tastes along postulated scales without testing their construct validity would be a rather unscientific approach. Note that this inadequate approach corresponds to a common procedure in emotion psychology, in which participants rate stimuli along predefined scales which have not been validated beforehand.

If our approach towards taste space is to be as unbiased as possible, with respect to potential dimensions, and if in addition we wish to test whether a dimensional space exists at all, multidimensional scaling (MDS, [8,9]) is a good choice. The following experiment collects pair data on the similarity of the taste of liquids that are suitable for MDS.

The choice of liquids was inspired by the common observation that sweet and sour are often perceived as antagonistic. If a person is asked "What is the opposite of sweet?" the most frequent answer would be "sour". Therefore, the following experiment tests a subspace of the taste space, the sweet–sour space.

A. Methods

Nine liquids were prepared along a 3×3 scheme, with three concentrations of sugar (10, 30, or 60 sugar cubes [2.8 g] per liter) and three concentrations of lemon juice (20, 60, or 120 ml per liter). A visualization of the 3×3 scheme of the liquids can be seen in Fig. 1c. Note that by using liquids of known composition this setting deviates profoundly from experiments in emotion psychology where the ingredients of a stimulus appealing to a specific emotional dimension are generally not known.

MDS requires similarity data for all the possible pairs of these nine liquids, which is 36 pairs of liquids. In a classroom experiment, 52 participants of a psychology class tested four different pairs each (taken randomly from the 36 possible pairs) of these nine liquids. The participants rated the dissimilarity on a scale ranging from 0 (no difference perceptible) to 4 (extreme difference). In total, 208 judgments were gathered, i.e., on average five to six ratings per pair.

B. *Data Analysis*

The similarity data were subjected to a nonmetric MDS analysis. This approach assumes that there is a representation of the items (the nine liquids) in a multidimensional space. This representation should reflect the similarity data in such a way that similar items lie close to each other in the dimensional space, whereas dissimilar items are far apart from each other. It is assumed that the 36 pairs reveal a monotonically increasing relation of distance as a function of dissimilarity. For any given configuration (position of the nine items in the multidimensional space) one calculates the deviation from the monotonicity of the distance-dissimilarity function, the so-called stress [9]. It is renormalized by the distances present in the configuration and comes as a fraction, representing the part of the variance not explained by the best fitting monotonous function. An optimizing procedure then finds the configuration that yields the minimum stress for the given data.

C. *Results and Interpretation*

With an increasing number of dimensions, the stress decreases (0.25, 0.13, and 0.08 for one, two, and three dimensions). This is to be expected, as more dimensions result in more degrees of freedom for finding a low-stress configuration. In order to verify whether the gustatory data support a dimensional interpretation, their stress values were compared to the stress values for the optimal configurations for random data. In this analysis, it was assumed that the similarity data of the 36 pairs would not reflect any dimensional structure. Instead, they were randomly resampled from the experimental data. The MDS algorithm will nevertheless find a configuration that gives minimum stress. The stress of the optimal configuration for the real data should be significantly lower than the stress of the optimal configuration for the resampled data, as long as the real data, in some way, reflect the dimensional structure of an underlying space. Note that this test is more rigorous than the usual comparison with simulated configurations with predefined error rates (cf. [10]).

The gustatory data support a one- and a two-dimensional interpretation. The mean of the stress values for the optimal one-dimensional configurations for resampled data is 0.36, with a lower one-sided 95% confidence interval of 0.30. The experimental stress value (0.25) is significantly lower ($p \leq 0.005$). The same holds for two dimensions (mean of stress values for resampled data: 0.17, lower bound: 0.13, experimental value: 0.126, $p \leq 0.05$). The three-dimensional interpretation is not corroborated because the stress value (0.08) is not significantly different from the ensemble of stress values obtained for random data (mean of stress values for resampled data: 0.09, lower bound: 0.06, $p > 0.1$).

Fig. 1 shows dimensional representations of the gustatory data. In Fig. 1a we see the one-dimensional configuration. What could be a possible interpretation of this dimension? At the one end of the scale, we find item 7, which is the liquid with the highest concentration of lemon juice and the lowest concentration of sugar. It will undoubtedly taste rather sour. At the other end of the scale, we find item 3, which is the liquid with the highest concentration of sugar and the lowest concentration of lemon juice and will certainly taste very sweet. The most prominent dimension of the gustatory space covered by those nine liquids seems to be the sour–sweet dimension.

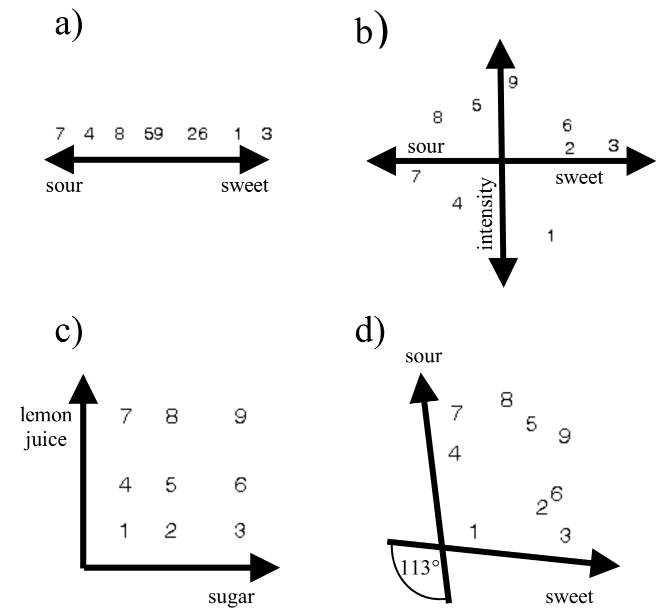

Figure 1. Stimulus configuration and MDS configurations. a) One-dimensional configuration and its interpretation along a sour-sweet dimension. b) Two-dimensional configuration and its interpretation featuring a sour-sweet and an intensity dimension. c) Stimulus configuration. d) Two-dimensional configuration turned such as to correspond closely to the stimulus configuration. The positions of the axes follow from a correlation analysis, correlating the item positions with the concentrations of the substances.

In view of the stress values it seems legitimate to consider the second dimension. Fig. 1b shows the two-dimensional configuration. This configuration is rotation-invariant. In Fig. 1b it is presented such that the variance of the horizontal positions of the items is maximized, and the variance of the vertical positions is minimized. This is a common criterion when deciding about the appropriate rotation.

Again, we have items 7 and 3 being the most distant ones, their distance being oriented along the horizontal axis. This axis corresponds closely to the sweet–sour dimension supposedly found in the one-dimensional configuration. What would be the interpretation of the additional dimension now shown by the vertical axis? The topmost item is liquid 9, the one with the highest total amount of substance (sugar and lemon juice) in it. The lowest item, on the other hand, represents the liquid with the lowest amount of substance in it. In this experiment, it appears that the second dimension of the gustatory space would be a kind of intensity dimension.

D. *Alternative Interpretation*

The basic mechanisms of taste perception have been well researched in the past. The effects of sugar and lemon juice on their specific receptors are well known. It is therefore interesting to compare the two-dimensional configuration of the MDS analysis (Fig. 1b) with the two-dimensional representation of "stimulus space" (Fig. 1c). The latter describes the concentration of two substances that excite two different receptor types independently. It could be compared to cone excitation spaces or to color spaces derived from linear color mixing, and would represent the structure of taste space derived from linear mixing. Would it be possible to find the two stimulus axes of Fig. 1c in the two-dimensional configuration presented in Fig. 1b?

In Fig. 1d we see the same configuration as in Fig. 1b, rotated in order to correspond closely to the stimulus configuration (Fig. 1c). The axes drawn in Fig. 1d represent the experimentally measured bases of the cognitive sweet-sour coordinate system. They were determined by means of a correlation analysis. In a non-orthogonal coordinate system the direction of a certain coordinate X does not represent the direction of the greatest rate of increase (gradient) of X but the direction "where it is only X that matters", i.e., where the influence of the other coordinates is minimal. The correlation analysis aims at finding this direction. The items of the two-dimensional MDS configuration were collapsed into one-dimensional projections of various orientations, i.e., with the angles of the projection varying from 0 to 360 degrees. The positions of the items on this projection were then correlated with the linear or logarithmic concentrations of sugar and lemon juice. For each substance there was a direction of maximum and of minimum correlation. The substance axes (bases) of the sweet-sour coordinate system are chosen such as to represent the direction of minimum correlation with the respective other substance. The linear and the logarithmic analysis show quite similar results. As a result of this correlation analysis, the sour axis represents the effect of lemon juice unaffected by the amount of sugar in the liquid, and vice versa.

It turns out that the two-dimensional MDS configuration corresponds rather well to the stimulus configuration. Fig. 1d shows the axis positions resulting from the correlation with the logarithmic concentrations. The coordinates of the nine liquids in the coordinate system spanned by the two axes correlate highly (sugar axis: $r = .98$, lemon juice axis: $r = .91$) to the logarithmic concentration of the two substances. The correlations with the coordinates following from the linear analysis (not shown) are slightly lower (sugar axis: $r = .93$, lemon juice axis: $r = .89$). Apparently, the two axes in Fig. 1d are not orthogonal. The angle included between them is 113° instead of 90°. From the view of gustatory science it is highly remarkable that there is a slight tendency of sweet and sour tastes to be more dissimilar than one would expect, given that the processing of sweet and sour tastes by their receptors is independent. This interesting finding arises from comparing the configuration resulting from MDS (i.e., from perceptual similarity judgments) with stimulus space, a construct based on solid knowledge of gustatory physiology.

III. Discussion

Dimensional analysis of mental phenomena, such as percepts (color, taste) or emotions, is in general based on cognitive tasks, such as absolute judgment (rating) or comparisons (similarity data, differential thresholds). The resulting dimensional spaces will describe the structure of the cognitive representations of the mental phenomenon under study rather than some structure of this phenomenon itself. It could be that important aspects of the results reflect general aspects of cognitive processing rather than special aspects of the mental phenomenon under study. This is even more relevant when the analysis refers more to the memory of the phenomenon under question than to the phenomenon itself, as is the case with most studies in emotion science. Pictures of the International Affective Picture System (IAPS, [11]) will in general not elicit strong emotions but evoke memories of emotions, and ratings or comparisons will be based on these memories. However, even if we acknowledge the fact that dimensional analysis is concerned more with cognitive representations than with emotions (or color, or taste), there are a number of caveats and objections to dimensional analysis that should be considered.

The first remark is a caveat. It concerns methodology and is relevant to the dimensional analysis of any mental phenomenon. Whereas a dimensional analysis has not yet been considered in taste science, the structure of color space is a prominent topic in color science. However, there is no consensus on the structure of color space. Reference [12] discusses the various approaches to defining the metrics of color space. Color spaces may be derived from laws of linear color mixing, requiring that additive mixtures of two colored lights fall on a straight line between these two lights. This results in color spaces, like the CIEXYZ color space. A linear transform of the CIEXYZ color space yields the so-called cone excitation space which is thought to represent the wavelength sensitivity of the three types of cones. However, such color spaces do not correctly represent perceptual differences. The best-known example is the discrimination ellipses measured by [13], the size and orientation of which varies widely across the CIEXYZ color map. By non-linear compression, the CIEXYZ space can be transformed in order to better represent perceptual differences, leading to a color space called CIELAB 1976. In the CIELAB 1976 space, additive mixtures will no longer fall on straight lines. Perceptual differences still are not perfectly represented. When trying to define a color space in order to truly represent perceptual differences, it shows that this space has to be non-Euclidian [13]. It will also neither represent cone excitation, nor reflect the effects of linear color mixing.

Obviously, there is no such thing as "the one and only color space". This observation should be a caveat for any researcher trying to conceive a dimensional space for some other modality. The first thing to do would be to decide whether the space should represent perceptual differences, or predict the effect of mixing. There are possibly more criteria upon which a space could be built. In the literature on "emotion spaces" no such discussion has ever taken place. Moreover, one should be prepared to end up with a non-Euclidian space. This is also something which has not generally been considered in emotion science (for an exception see [14]) .

A second caveat should be taken into account when attempting to assess dimensional spaces of mental phenomena. It has often been observed that the MDS analysis seems to be limited to about three dimensions. In a study on timbre it was found [15] that two subsets of the stimuli (percussive versus harmonic timbres) revealed a high number of dimensions in timbre space. However, the superset containing all stimuli did not span a space with a number of dimensions equal to the sum of the number of dimensions of the subspaces. It seems to be impossible to maintain a cognitive representation of similarities and dissimilarities that corresponds to a five-dimensional space. Given the richness of emotional phenomena, it seems especially inappropriate to try to fit all emotions into a low-dimensional space. The (low-dimensional) result of dimensional analysis might tell us more about our cognitive abilities to represent similarities of a diverse set of emotions (or timbres) than about emotional processes. This caveat is not only important for MDS analysis, but for all attempts to asses a dimensional space by means of cognitive tasks.

The major objection presented in this paper is about a lack of basic knowledge. For the moment, let us dismiss the difficulty of deciding on the criterion (just noticeable differences, similarity ratings, linear mixture) used to derive a certain dimensional structure. Let us suppose that we found a good reason to select one of these methods over the others, and that we were able to measure the dimensional structure. What can be learned from this approach?

The potential knowledge gain depends strongly on what is known about the underlying processes. If we do not know enough about the basic processes that lead to the cognitive representations that we are scaling, the result of our scaling analysis might be heavily misleading. Let us consider the lesson learnt in the experiment presented in this paper. The knowledge-blind dimensional analysis of the gustatory space presented in Fig. 1a and 1b suggests that sweet and sour tastes are the opposite end points on a sweet-sour scale. This conclusion would, however, be a big mistake. Sweet is not the opposite of sour; unlike opponent colors (there is no greenish red) sweet and sour tastes may coexist. However, if we take into account what is already known on the basic mechanisms of taste perception, we arrive at an alternative and much more fruitful interpretation (Fig. 1d). At some higher level, the cognitive representation of sweet and sour is apparently affected by some interaction of yet unknown origin. Sweet and sour tastes interact. The angle between the axes in Fig. 1d is 113°. It does not even come close to 180°, which would be the angle that corresponds to the much stronger notion that sweet and sour tastes were opposites and would justify the notion of a sweet-sour axis as was presumed in the interpretations of Fig. 1a and 1b.

There is nothing wrong with the two-dimensional configuration shown in Fig. 1b. The problem lies in its interpretation. The interpretation presented in Fig. 1b might be more harmful than helpful when trying to understand the mechanisms underlying taste perception. As with Alexander Pope, we could state that a little learning is a dangerous thing. It is only due to our knowledge on specific substances, which elicit basic tastes, that we were able to derive a different interpretation of the same configuration presented in Fig. 1d, which reveals sweet and sour as nearly, but not perfectly independent tastes. The slight antagonism of sweet and sour tastes might be considered an interesting topic of gustatory science deserving further study. Due to our previous knowledge on basic tastes we could interpret the data in a way that might inspire future research.

Also in color science, there exists a profound knowledge base on the physiological processes underlying color vision. The receptors are known, and the degree of excitation of each receptor type can be predicted from the spectrum of the incoming light. There is no question that a color space (whatever method is used to construct it) should feature exactly three dimensions. The structure of color space can be compared to what is known on the physiology of color vision at various stages of processing (receptor cells, bipolar cells, V1, etc.). Color space is thus linked to basic physiological processes of color perception.

In emotion psychology, however, the situation is much less favorable. Are there basic emotions, and if so, how many of them? What would be a good criterion to include a potential candidate in the list of basic emotions? Gustatory science has a clear-cut criterion for this decision: The criterion that distinguishes a basic quality from other non-basic sensations, such as astringency (tannins) or metallicness (Cu2+), is the presence of a specific receptor for this taste on the tongue. There is no consensus on such a criterion in emotion psychology. Given the ignorance on the existence and/or nature of specific stimuli for these basic emotions, it would be difficult to determine a "stimulus space" (such as Fig. 1c in the gustatory case) and compare it to the output of the dimensional analysis of the cognitive representation of the resulting emotions. In gustatory science we know that sugar is a good way to stimulate the sweetness receptors. In emotion research, dimensional analysis is carried out using sets of stimuli of which we do not consider in advance the emotion that they should elicit (pictures of the IAPS database, for instance; the values for valence, arousal, and dominance follow from ratings, they are not known or predicted beforehand).

Finally, let me ask the question of meaning of dimensional analysis. Why should we want to describe emotions along a certain number of dimensions after all? Given the difficulties in method and interpretation it seems legitimate to examine the purpose of the information reduction achieved by a dimensional approach. In color science, the reduction of the infinite-dimensional space of spectral colors to a three-dimensional space corresponds to the psychophysical evidence. This becomes clear when considering the concept of metamerism. This concept refers to the fact that different spectral power distributions may elicit perfectly matching apparent colors. Metamerism is the precondition on which any color space is built. Metameric colors occupy the same point in any color space, and they are indistinguishable to the observer. A similar concept could be defined in taste science, at least for odorless liquids: different chemical substances (sucrose and dextrose) may elicit identical apparent tastes. Different stimuli in the IAPS database, however, may feature comparable values on the three dimensions reported for this database, namely valence, arousal, and dominance, and nonetheless appeal to quite different emotional processes. For instance, slide 4531 shows an erotic male, and slide 7351 shows a pizza (see Fig. 2). Now consider their

Figure 2. IAPS slides 4531 and 7351, showing an erotic male and a pizza. These two pictures are rated very similarly on the three IAPS scales valence, arousal, and dominance. It is safe to assume that they will elicit quite different emotions in most viewers.

positions in the three-dimensional "emotion space" spanned by the nine-points scales for valence, arousal, and dominance. The maximum distance is eight along a single dimension, and 13.9 along the space diagonal. The positions of slide 4531 and 7351 are very close to each other. They are both rated 5.8 on the valence scale and 4.3 on the arousal scale, and 5.9 versus 6.0 on the dominance scale. The Euclidian distance between them is 0.1. Given the uncertainties related to the rating on those three scales (the standard deviations of the ratings for these two pictures are between 1.7 and 2.8 points on the three scales) they can be considered to occupy virtually the same point in the three-dimensional "emotion space". However, it can safely be assumed that a picture of a pizza and a picture of an erotic male will elicit quite different emotions in most individuals. They should not be considered metameric.

The world of emotions is much richer than the world of colors or the world of odorless tastes. Whereas in color science and in taste science, the information reduction inherent to dimensional analysis is appropriate for the object of investigation, this is not the case for emotion science which should refrain from any attempts to reduce the complexity of emotional life more than necessary. Theories emphasizing the role of basic emotions may have quite similar problems (for a critical review see [16]). The assumption of a single basic emotion called "joy" – of what? good food? good company? good music? – may be as problematic as the assumption of a unique pleasure dimension.

What we need is much more information on the psychophysiology of basic emotional processes. This information is interesting per se, and it will contribute to the understanding of the interplay of these subconscious processes and the cognitive representations of emotions, which is the declared goal of, e.g., appraisal theories [17,18]. It will not necessarily support dimensional analysis.

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