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PII: S0308-8146(96)00027-1

Food Chemistry, Vol. 56, No. 3, pp. 303-311, 1996

0308-8146/96 $15.00+.00

Individual differences in taste perception

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(Received 22 September 1995; revised version received 5 December 1995; accepted 5 December 1995)

Individual differences in taste perception require careful attention by researchers. These are differences between people which are produced, for example, by such easily identified variables as gender, age, and some genetic differences, and more subtle ones, such as those associated with personality types. They are often treated as nuisance variables. However, if ignored, they affect the validity of descriptions of effects and thus generalizations, since measures of central tendency do not well reflect heterogeneous distributions. They can reduce the power of statistical tests; null hypotheses are accepted more often than they should be. Individual differences provide evidence about the nature of mechanisms underlying sensory phenomena, and thus are important in the generation of research hypotheses. Simple analyses of distributions of measures within groups often fail to identify subgroups; theory and observations from prior work may be necessary to identify variables producing individual differences. Many sources of individual differences in sensory studies have been identified. These include genetic endowment, age and personality, as defined by various psychological tests. In studies of taste, smell and oral irritation, individual differences have been found in absolute and differential sensitivity, perceived quality, hedonic ratings, identification, rate of salivation, and relative sensitivity of receptor loci.

INDIVIDUAL DIFFERENCES, STATISTICS, AND EXPERIMENTAL DESIGN

Individual differences are often considered annoying sources of variance in research. They are referred to as nuisance variables since, if unrecognized, they may obscure the effects of experimental treatments, and bias the interpretation of effects.

Individual differences and description

Descriptive statistics are used to characterize the results of studies in order to think about them. The characterization must be valid for the thoughts to be valid. Usually a measure of central tendency, most often the arithmetic mean, is utilized to describe groups. This and other measures of central tendency are appropriate only if the distribution of scores of the group being described is symmetrical and unimodal.

The need for data reduction by some measure of central tendency is a very real one, but the use of the measure where unwarranted will produce an inaccurate description and thus invalid generalization and inferences. If there are systematic individual differences in the groups being described, a mean or other measure of central tendency is likely to be an invalid statistic.

Individual differences and power

Individual differences affect the efficiency of statistical tests utilized to evaluate the effects of experimental treatments. In both parametric and non-parametric statistical tests the standard by which the impact of treatment effects are measured is within-group variance, i.e. the variation found within groups that have identical experimental treatment. People treated the same way should respond the same way. Thus, the extent to which they do not is viewed as experimental error. The size of variation in data due to treatments is judged against the amount of variation within groups treated similarly. Thus, the larger the differences within a group receiving the same treatment relative to differences due to treatment effects, the less likely one is to detect, and to determine as statistically significant, a treatment effect.

This failure to detect treatment effects that in fact exist in the population being sampled is called a Type II error. The statistical power of a statistical test is the probability of not making a Type II error.

Removal of unwanted variation

The removal of both systematic and non-systematic (random) variation within groups is desirable since it increases both the ability to generalize from results and the statistical power of analyses. There are two ways to remove unwanted variance. One way is to hold the source of variance constant and this method is often used. Research is conducted in environments in which all controllable variables are held constant, with specially trained and selected panels. Homogeneity of sample is emphasized. With little or no variance from situational and subject variables affecting the data, they should be relatively free of contamination by nuisance variables. However, generalization from such studies can be risky. The results can be generalized only if there is no interaction between the experimental variable(s) manipulated and the variables that were held constant. Commonly, workers will hold potential nuisance variables constant by using a highly trained panel of judges, for example, but then attempt to generalize to a general, more diverse, population. They are puzzled when their findings do not replicate and predictions fail. Error variance was reduced but at the cost of generalizability. This lack of ecological or external validity that occurs when findings from laboratories are inappropriately generalized to field conditions is not uncommon.

Clearly, the experimenter is in a bind; he must hold variables constant to reduce within-group error and have an acceptable level of power, but if one or more of those controlled variables interact with the experimental, manipulated variable, valid generalizations to the relevant population may be invalid. Thus it is reasonable to select subjects for research on taste who have good oral health because generalization only to healthy individuals is reasonable, but it is not reasonable to select subjects of only one gender if you wish to generalize to both women and men.

The other way to remove within-group variance is to incorporate the variance contributing to the individual differences into the analysis. Rather than try to hold the source of the variance constant, one identifies the source and statistically isolates the variance produced by it from the data. Those variables thought to be responsible for individual differences are treated as non-interacting independent variables along with the treatment variable(s). Now the effects of the nuisance variable will be removed from the within-group variance and, in addition, the magnitude of that variance can be evaluated. For example, one might be studying the sweetness of mixtures of fructose and sucrose. Assume that there are individual differences in response biases; some subjects give responses smaller than warranted by the sweetness they sense, and others give responses larger than warranted. These differences would be included in the within-group variance used to assess the effect on sweetness of mixing sweeteners.

The effects of these individual differences can be removed from contamination of the analysis by independently classifying the subjects into, for example, those whose response biases are positive, neutral and negative on the basis of an independent test. The statistical analysis would then include an assessment of the bias and remove its effects from the within-group variance used to evaluate the relative size of the effects of adaptation. In analysis of variance, randomized-block experimental designs accomplish this. If the bias were found to be trivial and its isolation did not appreciably affect the within-group variance, there is no cost to the experimenter as that trivial variance can be pooled with the within-group variance to increase the power of the test through increasing the degrees of freedom.

Furthermore, not all individual differences are truly nuisance variables. If individual differences interact with experimental variables, they are indications of relevant causal variables, i.e. factors that vary across people and importantly affect the responses under investigation. These variables must be accounted for in order to understand fully the phenomenon under investigation. Thus, individual differences are often the source of principal hypotheses. In chemosensory work, individual differences can be seen as evidence for differences in mechanisms underlying sensory phenomena of interest.

IDENTIFICATION OF INDIVIDUAL DIFFERENCES

Generally, there are two ways to identify the sources of individual differences: inspection of data, and use of prior knowledge and theory.

Inspection

If the distribution of data is bimodal, multimodal, or unsymmetrical, the data should be examined for subpopulations responsible for the modes or lack of symmetry. However, there may be relatively distinct subpopulations within unimodal, symmetric distributions. It is not necessary that the presence of subpopulations be revealed by the shape of frequency distributions. For example, Fig. 1 shows the frequency distributions for two samples of 200 data points randomly drawn from normal populations having about the same standard deviations but with means 14 standard errors apart, and for the distribution of the two samples combined. The probability of the samples

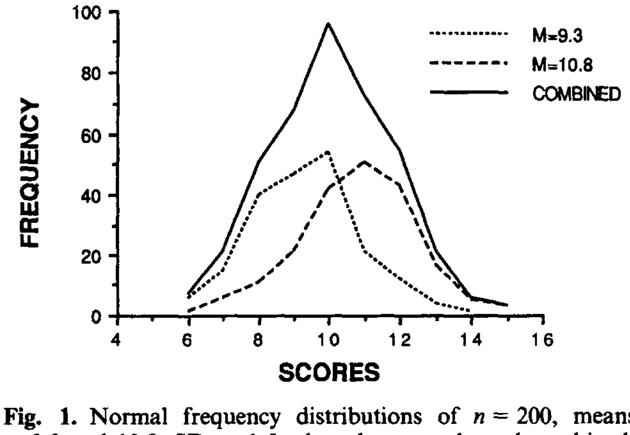

Fig. 1. Normal frequency distributions of $n = 200$, means $= 9.3$ and 10.8, SDs $= 1.5$, plotted separately and combined. (Reprinted from Stevens, 1991*b*, p. 300, by permission of Marcel Dekker Inc.)

having been drawn by chance from the same population is less than 0.001 ($t = 9.2$, $df = 398$). Yet, when the distributions are combined, the result is not bimodal. Here, the shape of the distribution fails to indicate that it is formed of two different subgroups.

Figure 2 shows the same subgroups but with means now 30 standard errors apart. The combined subgroups now show a bimodal distribution, but it is hardly the obvious bimodal distribution that textbooks lead one to expect from the addition of such different subgroups. Clearly, the inspection of distributions of populations containing subpopulations will not always suggest the existence of those subpopulations in them.

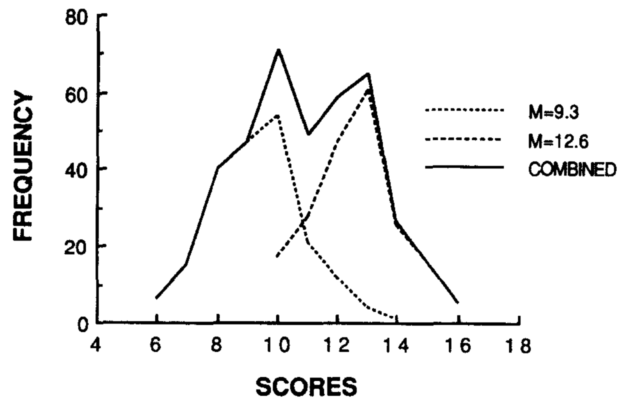

Fig. 2. Normal frequency distributions of $n = 200$, means = 9.3 and 12.6, SDs = 1.5, plotted separately and combined. (Reprinted from Stevens, 1991*b*, p. 301, by permission of Marcel Dekker Inc.)

Individual differences from general, established sources

Since a general inspection cannot be relied upon to indicate the existence of subgroups, prior knowledge or theory about the sensory phenomenon can suggest that particular systematic individual differences exist. These sources of variance may be potential, i.e. suggested by theory, but not yet shown to be effective sources, or they may be known sources. Often, known sources are general ones such as gender or age. However, general sources define a number of variables. For example, currently, gender defines differences in perceived expectancies, environments, opportunities, income level, interactions with children, and experience in food selection and preparation, and many other variables in addition to genetic, hormonal and anatomical differences. Similarly, as chronological age varies, so do sensory functions, cognitive functions, motor skills, etc. Since there is this nesting of variables within general ones, the design of a study using a general independent variable should include controls for variables correlated with the general one that might confound a more specific variable of interest. Often this must be done indirectly, rather than directly. For example, you cannot hold your subjects' histories constant, but you may be able to show that particular confoundings of historical variables do not affect your results. Identification of those that do affect your results can enable the adjustment of data statistically or permit appropriate qualifications in interpretation.

Individual differences in sensory phenomena are subject to confounding by differences in the perceptual organization of the sensations, and in the responses to the stimuli. When one person reports a substance as less sweet than does another person, the difference could well be in the cognitive interpretation of the sensations, or in the reporting of the sweetness, rather than in the sensations of sweetness *per se*. The common confusion by subjects of sweetness and pleasantness is an example of this confounding.

Other examples are found in earlier studies of age differences in flavour perception where it was not clear if the results were due to sensory differences, differences in people's concepts about foods, or some interaction of them. Accordingly, Stevens & Lawless (1981) examined the perceptual basis of flavour in three age groups: 18–25 years, 36–45 years, and 56–65 years, including a control for the subjects' conceptions of food flavours.

The subjects tasted all possible pairs of 12 purees of unseasoned fruits and vegetables and were asked to rate the pairs on their similarity of flavour. Similarity ratings have the advantage of being free of external bias as no list of attributes was provided by the researcher; the subjects must generate the bases of the judgments on their own. To provide an objective basis for interpretation of the analysis, after the similarity ratings were completed the subjects were asked to list the attributes they generated. On the following day the purees were again tasted and rated using the most frequently mentioned attributes. To obtain an assessment of age differences in food concepts, we also had the subjects rate the similarity of flavours of the purees using only the purees' names. Judgments from tasted foods could be then compared with judgments based only on their names. Multi-dimensional scaling (ALSCAL) then put the objects (purees) in multi-dimensional space, with the distances between objects corresponding to the similarities; foods judged to be similarly flavoured were thus placed close together; those judged to be different were further apart. The number of spatial dimensions needed for an efficient solution presumably represents the number of perceptual dimensions utilized by the subject, and the array of objects within the space indicates the definition of the dimensions. The attribute ratings served as dependent variables in multiple regressions over the coordinates describing the purees' locations in space, providing attribute vectors.

Four-dimensional solutions efficiently described the judgments of each age group. These are shown in Fig. 3; the dashed lines and their labels are the attribute vectors. For the younger group, sweetness and hedonics were highly correlated and defined a single dimension. However, for the middle group, hedonics and sweetness were now independent; sweetness did not predict hedonic quality for the 36- to 45-year-olds. In the older group neither sweetness nor hedonics were principal dimensions. For that group, intensities of attributes were important.

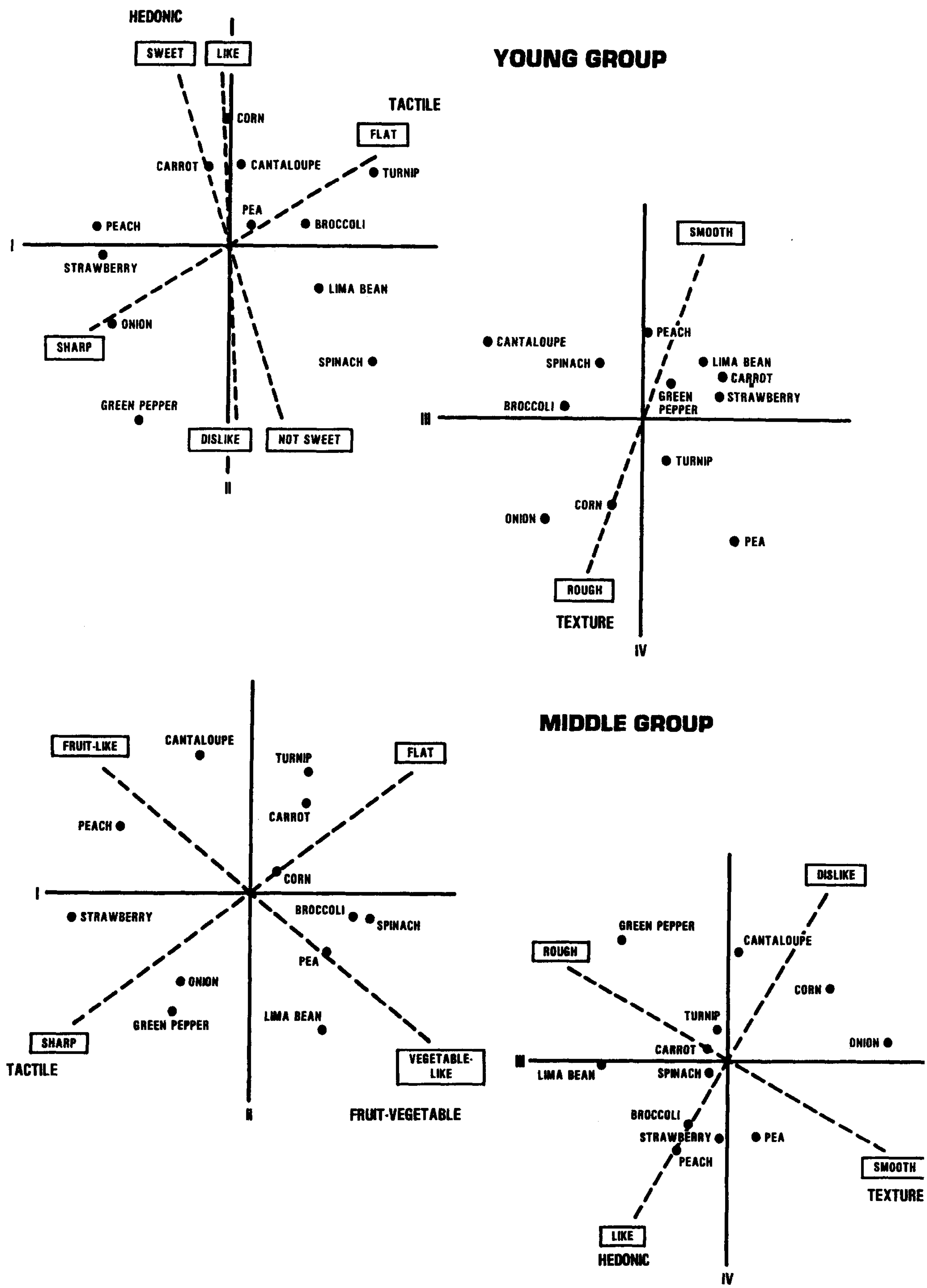

Fig. 3. Projections of MDS solutions for purees judged by three age groups. The dashed lines are attribute vectors produced by multiple regression with appropriate terminal descriptors. The labels are the interpreted dimensions. (Reprinted from Stevens & Lawless, 1981, pp. 130–1, by permission of Academic Press Inc.)

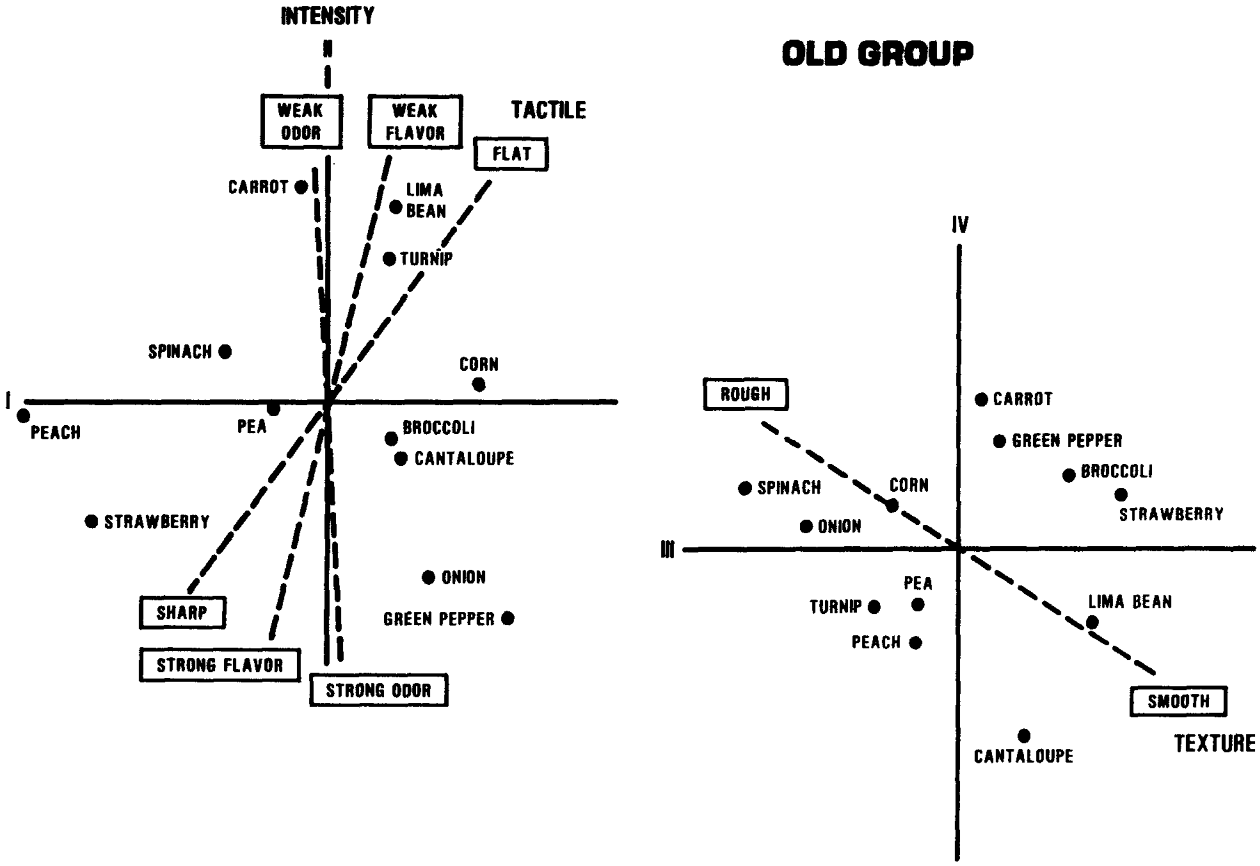

Fig. 3. *Continued*

There were no age differences in judgments based on food names. Concepts about food based on names remained stable over age, and thus the group differences we found cannot be attributable to differences in ideas about the flavours of the foods.

These differences in flavour perception are interesting, for there are generally relatively small suprathreshold age effects for taste, except for bitterness, using model solutions of tastants. For olfactory sensitivity, there are also relatively small effects up to around age 65. But despite the lack of large psychophysical differences through late middle age, we found important differences in the dimensions used by people in discriminating foods. Apparently, the way sensory information is used to produce the perceptions of flavour changes with age. It seems likely that this is more a result of experience, rather than chronology *per se*.

Theoretically suggested sources

Some work of the author's performed a few years ago is a good example of the use of a theoretically identified source of variance due to individual differences. It used a classification of people from a self-attribution theory of personality.

Following the theory of emotion of James (1884), theorists (e.g. Bem, 1967) have argued that people determine their own moods and feelings the same way they determine them in others — by assessing their own actions in context, and using that assessment to infer their mood. For example, people feel happy because they are smiling in a situation in which happiness is typical. They perceive their smiling, know that smiling is associated with happiness, and thus attribute their smiling to happiness. The traditional view of emotion differs. It states that some emotional stimulus elicits feelings, which are followed by appropriate actions. For example, meeting a bear in the woods (stimulus) evokes fear (feeling), resulting in a look of panic, change in heart rate, and running from the bear (actions). James' view was that this traditional sequence is backwards. He theorized that emotional feelings follow the actions evoked by the emotional stimulus. For James, then, one sees the bear (stimulus), looks panicked, experiences increased heart rate, runs (actions), and then registers the feelings of fright through attribution. The feelings are the result of actions, not the cause. When this theory of emotion has been tested, there have been individual differences in the extent to which people respond in the way that the theory predicts they should. Laird & Bresler (1992), Laird & Crosby (1974), and Laird & Berglas (1975) have produced a revision of this general self-attribution theory which accounts for some of the individual differences seen in the tests.

Laird argues that people differ in the extent to which they use different types of cues in making attributions about themselves. Self-produced cues are those that arise from an individual's actions and personal properties (the smiling in the first example above). Situational cues are those that come from the environment, and include normative expectations; that a rose will have a pleasant floral odour, for example. The latter kind of cues seem to be used by everyone, but there are reliable differences in the extent to which people use self-produced cues in determining their own mood and feelings, and in assessing their abilities. When induced to perform the muscle movements associated with smiling and frowning, some people report strong emotional fluctuations corresponding to the manipulations of facial expression, and some do not. Those whose mood is affected by manipulation of facial expression are called self-produced cuers, and those who are relatively unaffected by the manipulations are called situational cuers.

The stimuli for taste, smell and flavour perception and the hedonic responses to those experiences include both self-produced and situational cues. The former include the mouth movements associated with chewing, salivation, swallowing and sniffing. The latter include expectations about the stimuli, e.g. information contained on a product's label and through personal or cultural prior experience.

Since typically there are unexplained individual differences in the perception of taste, smell and flavour, and there are both self-produced and situational cues involved in tasting and smelling, and there are individual differences in the extent to which these kinds of cues are used, it seemed reasonable to hypothesize that differences in the perception of tastes and smells are related to differences in the use of situational and self-produced cues. Two studies done on this idea will be summarized.

The first studied the relation between individual differences in the perception of flavour of a prepared food and personality types. In a factorial study in which stimuli that should provide self-produced and situational cues were independently manipulated (Stevens *et al.*, 1988; Stevens, 1990) the subjects were given samples of a chicken soup having sodium concentrations of 0.276% (normal), 0.420% (high), or 0.564% (very high). When these samples were presented the subjects were told the soup had 'less than normal flavouring', 'more than normal flavouring', or were told nothing. The sodium concentration was assumed to provide self-produced cues and the verbal information was assumed to be a situational cue. Using 150 mm line scales with labels of no, faint, moderate, strong, or very strong quality, the soups were tasted and rated on several attributes (e.g. flavour, pleasantness, oiliness).

The subjects were classified using a test of Private Body Consciousness (PBC) (Miller *et al.*, 1981). With the test, people are classified as having high or low PBC on the basis of their answers to questions on how sensitive they are to changes in body temperature, internal tensions, heart rate, dryness of mouth and throat, and hunger contractions. They were also classified for cuer type by the extent to which manipulation of facial muscles produced changes in mood (Duncan & Laird, 1980).

Those whose mood was most determined by facial manipulation were classified as self-produced cuers, and those whose mood was least determined by this were classified as situational cuers.

Analysis of the judgments of a soup's overall flavour showed that the self-produced cuers were more sensitive to the changes in sodium concentration than were the situational cuers for the intensity of the soup's flavour; the former had a steeper psychophysical slope (0.92, using log–log transformed data) than did the situational cuers (slope = 0.52). These results are shown in Fig. 4.

When the subjects were classified by PBC, similar results were found for judgments of intensities of saltiness. These are presented in Fig. 5. The participants showing high PBC were more sensitive to changes in sodium concentration (slope = 1.17) than were those with low PBC (slope = 0.84). Again, the groups differed in sensitivity in the expected direction. Studies have shown that self-produced cuers (Duncan & Laird, 1980) and people with high PBC (Brockner & Swap, 1983) show reverse placebo effects when others show the typical positive placebo effects. That is, they report feeling more rather than less anxiety when given a placebo to reduce anxiety. Presumably, being more aware of internal cues than others, these subjects realize that there has been no reduction in the symptoms and then reason that they

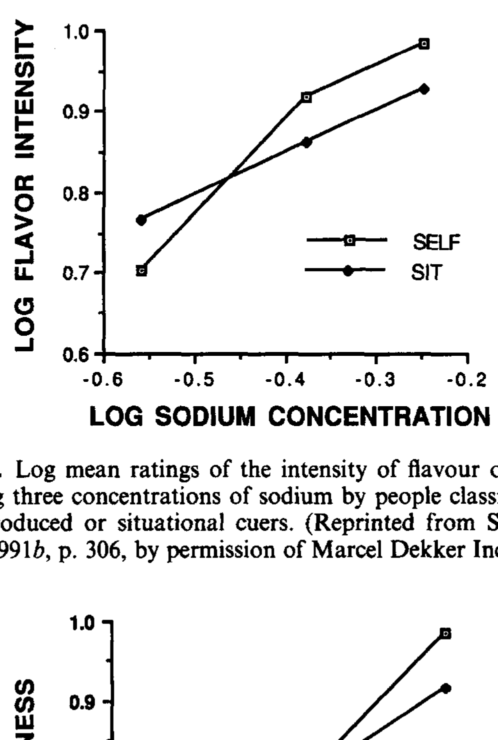

Fig. 4. Log mean ratings of the intensity of flavour of soup having three concentrations of sodium by people classified as self-produced or situational cuers. (Reprinted from Stevens, 1991*b*, p. 306, by permission of Marcel Dekker Inc.)

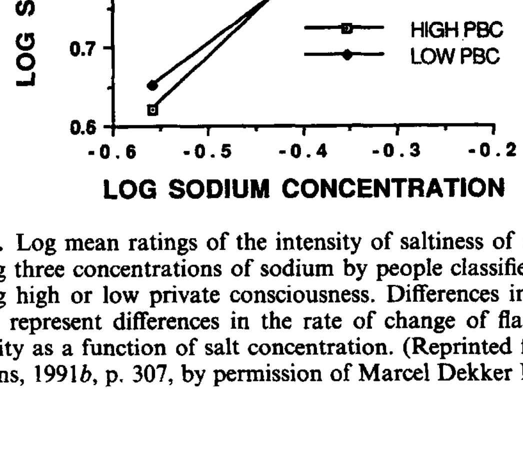

Fig. 5. Log mean ratings of the intensity of saltiness of soup having three concentrations of sodium by people classified as having high or low private consciousness. Differences in the slopes represent differences in the rate of change of flavour intensity as a function of salt concentration. (Reprinted from Stevens, 1991*b*, p. 307, by permission of Marcel Dekker Inc.)

must be more affected (i.e. sicker) than originally thought since the 'medicine' was not effective. Accordingly, a differential effect of verbal information was expected from those with high and low PBC, and indeed, different placebo effects were found for the two groups.

Figure 6 shows the hedonic responses of the two groups to soup samples with the lowest sodium concentration plotted as a function of the three kinds of verbal information given. A positive placebo effect for hedonic ratings was found for the low PBC subjects; they liked the soup verbally labelled 'flavour reduced' less than that labelled 'flavour added.'

From this and a number of other studies, it is clear, then, that people's judgments of the intensity of at least some tastes vary with the extent to which those people report being sensitive to some bodily responses (PBC) and differentially use cues in assessing their mood (self-produced and situational cueing). These effects are not due to general differences in response functions. There were no differences between the groups in responses to variables not manipulated, oiliness of soup, for example, and the groups did not differ for all of the manipulated variables. PBC classification showed differences only in saltiness and hedonics, and cue-type showed differences only in flavour intensity.

This work identified personality variables contributing to individual differences in flavour perception, but it did not identify the specific mechanisms underlying them. The differences in sensory responses between the self-produced and situational cuers may have their basis in the mouth movements used in tasting. It could be that proprioceptive stimuli (the sensations from oral and facial muscle movements) are the self-produced cues being used, or it could be that self-produced cuers have developed oral manipulations that result in a different flow of stimuli over the tongue. There is ample evidence that differences in stimulus flow affect the intensity of taste sensations.

The notion that cues related to mouth movements are responsible for the relationship between personality variables and psychophysical differences in taste was investigated by having people judge the intensity of four sets of five concentrations (0.12, 0.20, 0.31, 0.50 and 0.80 M) of aqueous sucrose solutions (Stevens, 1991*a*). For two of the sets, they were instructed to use exaggerated mouth movements. For the other two sets, they were to use their own normal movements. Tests for PBC were then given.

Analysis of variance of normalized geometric means of magnitude estimates of intensity of sweetness showed an interaction between the nature of mouth movements and level of PBC. The interaction is shown in Fig. 7. Unlike the subjects with low PBC, those with high PBC made higher estimates of sweetness when tasting with exaggerated mouth movements than they did with normal movements. It is unlikely that the verbal instruction itself, rather than the mouth movements, were responsible for the results as the high PBC subjects responded as one might expect from placebo effects. But, as noted above, *reverse* placebo effects have been found with high PBC subjects, not the usual placebo effects. The interpretation that it was mouth movements and not expectancies produced by the instructions given, is the only one consistent with prior findings of differences. These results do not address the question of whether it is differential use of proprioceptive stimuli from the mouth movements, or differences in the flow of tastants in the mouth produced by the movements that are responsible for observed differences among subjects. Further research will investigate this question.

This research is a example of how the recognition of individual differences contributes to the development of theory which in turn identifies other differences. Laird's theory of the differential utilization of self-produced and situational cues was developed because of individual differences in earlier studies of self-attribution theory; all people did not respond to self-produced cues in a similar manner. Laird's solution to that problem also explained some of the individual differences of unidentified origin typically found in chemosensory psychophysical studies. Broad similarities in the kinds of cues used by people in the self-attribution of emotion

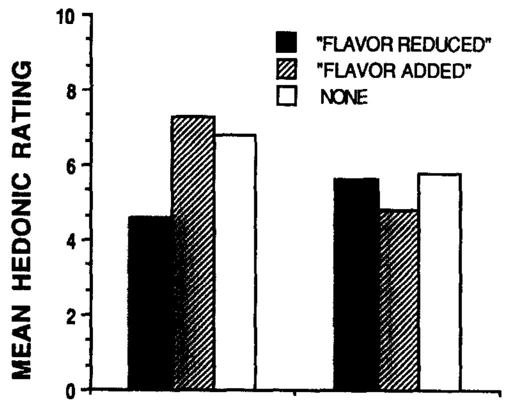

Fig. 6. Mean hedonic ratings of soup having a normal sodium concentration by people with high or low private body consciousness when given three kinds of verbal information about its flavour.

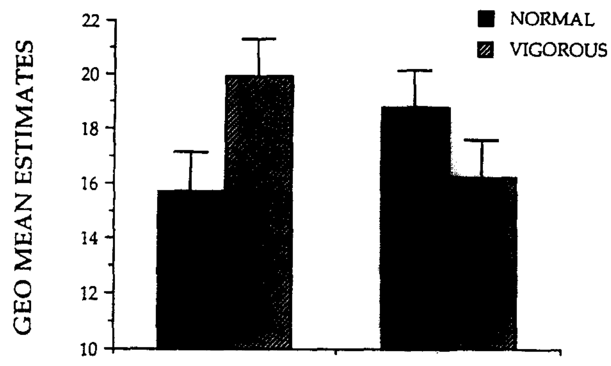

Fig. 7. Geometric mean magnitude estimates of the sweetness of sucrose solutions for subjects with high and low private body consciousness while tasting with normal and vigorous mouth movements.

and in flavour perception suggested that the same general explanation could account for differences in both domains. Rather than attributing individual differences in chemosensory perception to random error, they were investigated, and hypotheses developed from theory to account for some of them.

INDIVIDUAL DIFFERENCES USED TO DEVELOP AND TEST THEORY

There is a direct relation between the extent to which individual variation is found in sensory experiences, and the complexity of the underlying processes. The more complexity in the processes, the greater the opportunities for individual variation, be they primarily of genetic or of experiential origin. Thus individual differences suggest complexity, and complexity suggests that individual differences will be found.

Some recent work by Robert O'Connell and the author is an example of the former; individual differences in both the sensitivity to odorants and the quality of their odours were identified and used to support a multiple process notion of olfaction.

Pemenone, *cis*-4-(4′-*t*-butylcyclohexyl)-4-methyl-2-pentanone, produces a putrid, sweaty, urinous odour for most people, but for some it smells like green vegetables; for others it has a fruity or floral odour, and for some it has no odour at all.

In one study we screened several hundred subjects with a moderate concentration of pemenone and then selected groups of pemenone osmic and anosmic individuals (O'Connell *et al.*, 1989). These subjects produced magnitude estimates and quality reports for various suprathreshold concentrations of pemenone, androstenone (for which there are also individual differences in sensitivity and odour quality) and six other compounds. This study showed a positive relation between pemenone and androstenone and a negative one between pemenone and phenylethyl alcohol, which typically has a floral smell. A relation was also found between sensitivity and quality. Pemenone-osmic people, those for whom pemenone was relatively intense, were also likely to describe its odour quality as urinous. Anosmics, who found pemenone to have a relatively weak odour, were unlikely to describe its odour quality as urinous. Similar results were found in another study in which odorants at just liminal odour concentrations were evaluated to control for differences in magnitude of perceived intensity, as all the odours were about equally faint (Stevens & O'Connell, 1991).

Sensory adaptation refers to the diminution of sensation following exposure to a stimulus. For example, as one continues to sniff an odorant, the intensity of its odour decreases. This self-adaptation is usually held to be due to a reduction in receptor activity. Cross-adaptation, a reduction of sensation from one stimulus following prolonged stimulation by another is viewed as evidence for shared receptor processes. If cross-adaptation is less effective than self-adaptation, or if it is asymmetrical in its effects, the notion of multiple receptor processes is supported.

Recently we compared pemenone and androstenone as cross-adapters of one another and of isovaleric acid, another chemically unrelated putrid-smelling odorant, phenylethyl alcohol, and the green-vegetable-like pepper pyrazine. If one assumes that the number of different odour qualities elicited by an odorant within a general population of subjects is an indirect measure of the total number of different kinds of specific olfactory receptor processes involved with its perception, then, since pemenone has been described as urinous, floral, or herbal, it must normally interact with several classes of olfactory receptor neurons. An individual allosmic to pemenone, e.g. one who perceives a floral quality for pemenone, may do so because of a reduction in the number of receptor neurons normally sensitive to putrid compounds or because they have a proportionately greater number of receptor neurons normally responsive to floral odours. The inverse may be true for subjects normally osmic to pemenone in that they may have few olfactory receptor neurons responsive to floral odorants or a proportionately greater number of olfactory receptor neurons specifically responsive to urinous compounds. We reasoned that if pemenone and androstenone do interact with several kinds of receptors, then differences might be observed, after adaptation, in the intensity or perceived quality of those odorants that share the same pool of olfactory receptor neurons. Since the number of qualities elicited by pemenone is greater than those elicited by androstenone, we expected asymmetrical cross-adaptation by pemenone and androstenone. The former, being a more 'complex' odorant, should cross-adapt androstenone; the less complex androstenone, interacting with fewer coding channels, might not cross-adapt pemenone. Generally, that was what was found. Pemenone cross-adapted androstenone but androstenone did not cross-adapt pemenone. Neither pemenone nor androstenone cross-adapted the other modally putrid, floral or vegetable-like odorants used (O'Connell *et al.*, 1994; Stevens & O'Connell, 1995).

Collectively these observations suggest that the array of modally putrid, floral and vegetable odorants studied interacts with overlapping sets of specific olfactory receptor neurons which are, in turn, distributed in different proportions across individuals. In addition, the ability of pemenone to cross-adapt androstenone but not the other odorants which share the odour qualities of pemenone and androstenone, further suggests that those two odorants interact with the same set of olfactory receptor neurons. This work, which focused on individual differences in the odour of pemenone has uncovered unexpected relationships in olfactory perception that would have been difficult to find if differentiation by subjects had not been done.

Cross-adaptation studies of the sweet taste have also supported a multiple receptor model for sweetness. For example, some years ago Lawless & Stevens (1983) studied cross-adaptation by sucrose, saccharin, aspartame, and dihydrochalcone of each of the others. A single

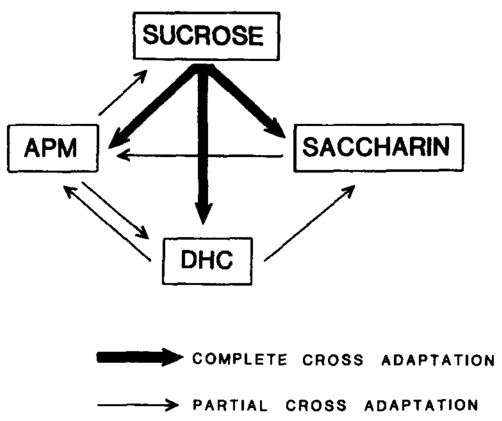

Fig. 8. Cross-adaptation of sucrose and three intensive sweeteners. Heavy lines indicate cross-adaptation equal to that of self-adaptation, thin lines indicate an intermediate amount of adaptation. (Reprinted from Lawless & Stevens, 1983, p. 313, by permission of Oxford University Press.)

peripheral mechanism for sweetness would predict uniform, symmetric cross-adaptation. However, the results, summarized in Fig. 8, showed complete cross-adaptation by sucrose of the three other sweeteners, but there was no or only partial adaptation by those sweeteners.

Adaptation studies are typically done in the intensive domain. Changes in threshold and suprathreshold intensities are studied, but investigations of the effects of adaptation on quality are rarely done. If the perceived quality of a chemical stimulus is coded by multiple receptor types, processes or mechanisms, then individual differences in quality shifts could occur. Examination of the quality of suprathreshold concentrations of sweeteners following exposure to other full or partially cross-adapting sweeteners would be of interest. The pattern of effects should shed light on the interactions that underlie the sensations of sweetness.

SUMMARY AND CONCLUSIONS

Individual differences are often treated as nuisance variables, i.e. viewed as contributing to within-group error, and thus an undesirable source of variation in the data. Often, systematic and unsystematic differences that do not interact with treatment effects do occur and are indeed nuisance variables. They should be controlled by holding them constant, at the risk of limiting generalization, or by statistically removing their influence, thus increasing statistical power. When individual differences do interact with other relevant sources of variance they should be studied, for the phenomena under investigation cannot be fully understood until the affects of the interactions, and the mechanisms underlying them, are known. Some sources of individual variation are obvious, but they are often general; age and gender are examples. General variables pose a problem as they define a group of nested variables that in turn should be controlled. Other sources of individual differences are not obvious, and the worker must use established relationships and theory to identify these potential sources.

ACKNOWLEDGEMENTS

The work described in this paper was supported by Biotechnology and Biological Science Research Council Award No. 5924 and EC-AIR Grant 94-2107.

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