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This e-paper contains the pre-circulated Abstracts, scripts and slides of two oral presentations to the joint meeting of the Canadian Society for Brain, Behaviour and Cognitive Science and the Experimental Psychology Society at the University of Toronto in July 1993 (given by RPJF).

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Contents of the PDF file

Email addresses (2010)
D.A.Booth@Bham.ac.UK
R.Freeman@ioe.ac.uk
M.T.Conner@leeds.ac.uk

ABSTRACT 331.9 from *Society for Neuroscience Abstracts* 1993
Poster at SfN Annual Meeting, Washington DC, November 1993

331.9

LEARNED SENSORY RECEPTOR PATTERNS CONTROLLING FOOD AND DRINK SELECTION AND INTAKE.

D.A. Booth*, R.P.J. Freeman, N.J. Richardson, M. Kendal-Reed. Psychology School, Univ. Birmingham, Edgbaston, Birmingham B15 2TT, U.K.

Moment-to-moment selection and hence the cumulative intake of familiar foods and drinks are controlled by the instantaneous discriminable distance for the individual between the current patterns of stimulation to (e.g.) gustatory, oritactile, olfactory, visceral and other receptors and the closest learned configural stimulus that elicits ingestive appetite or its satiety. This multidimensional signal-differences approach to the cognitive structure of ingestive behavior will be illustrated by recent findings for: (i) receptor-specific tastant mixtures occurring in natural foodstuffs; and receptor-profile stimulation (ii) tactually by the texture of dairy creams and (iii) olfactorily by volatiles mimicking fruit species. For example, the taste of orange is recognised in an appropriate proportion of sugars and acids in a drink, and this does not always depend on awareness of sweetness and sourness; the feel of cream in a milk depends on the sizes or spacings of the fat globules as well as on viscosity; closeness to real strawberries depends on the proportions of maltol, ethyl acetoacetate and cis-hexenol in the sniffed mixture. This method of behavioral analysis is likely to become important for the elucidation of both the sensory receptor types and the central pathways that control caloric and aqueous intakes (in Neurophysiology of ingestion, ed. D.A. Booth. Pergamon, 1993).

ABSTRACT for **Talk 1** at CSBBCS/EPS

INDIVIDUALS' INTEGRATION OF SENSORY AND SEMANTIC FEATURES IN DISCRIMINAL OBJECT-RECOGNITION SPACE.

R.P.J. Freeman and D A Booth. School of Psychology, University of Birmingham, Birmingham B15 2TT, UK.

The distinction between materially sensed percepts and percepts conceived in terms of general knowledge appears not to be crucial in psychometrically oriented multidimensional scaling. We illustrate here how psychophysically based analysis of recognition performance as the integration of discrimination-scaled features also bridges this distinction.

The material percept was the sweetness of an orange drink and the semantic percept was the sweetener name labelling the drink, either sugar or NutraSweet, assumed to be perceived as high and low in calories respectively. The simplest theoretical models of integration of responses from orthogonal discrimination axes were tested on judgements of preference, sweetness and calorie content. Those who usually or always used sugar drinks preferred their drinks less sweet but with a higher-calorie label. Those who used diet drinks preferred sweeter drinks but with a lower-calorie label. Drink calorie-content estimates were best explained by a two-dimensional perceptual integration process in female sugar users, whereas male diet-drink users' estimates were best explained by a process of calculation of calorie content from representations of both amount and calorie level of the sweetener.

CANADIAN SOCIETY FOR BRAIN, BEHAVIOUR, AND COGNITIVE SCIENCE

Joint meeting with the:
EXPERIMENTAL PSYCHOLOGY SOCIETY

University of Toronto
15 - 17 July 1993

Talk 1 at CSBBCS/EPS, U Toronto, July 1993

Individual integration of sensory and semantic features in discriminal object recognition space

RICHARD FREEMAN WITH DAVID BOOTH

Perceptible aspects of objects and situations that are of sufficient interest to a culture acquire names or a descriptive vocabulary. Some aspects may be sensed without conceptual mediation. For others, some semantic processing is a prerequisite for identification or characterisation.

Knowledge-contentful and knowledge-free descriptors of features of objects and situations may behave the same way grammatically but they seem to refer to very different kinds of percept. As a result, psychologists have divided Perception between the psychophysics of material qualities – 'sensory' features - and the recognition of meaningful attributes – 'semantic' features.

Yet this distinction may not be as unmanageable as it sometimes seems.

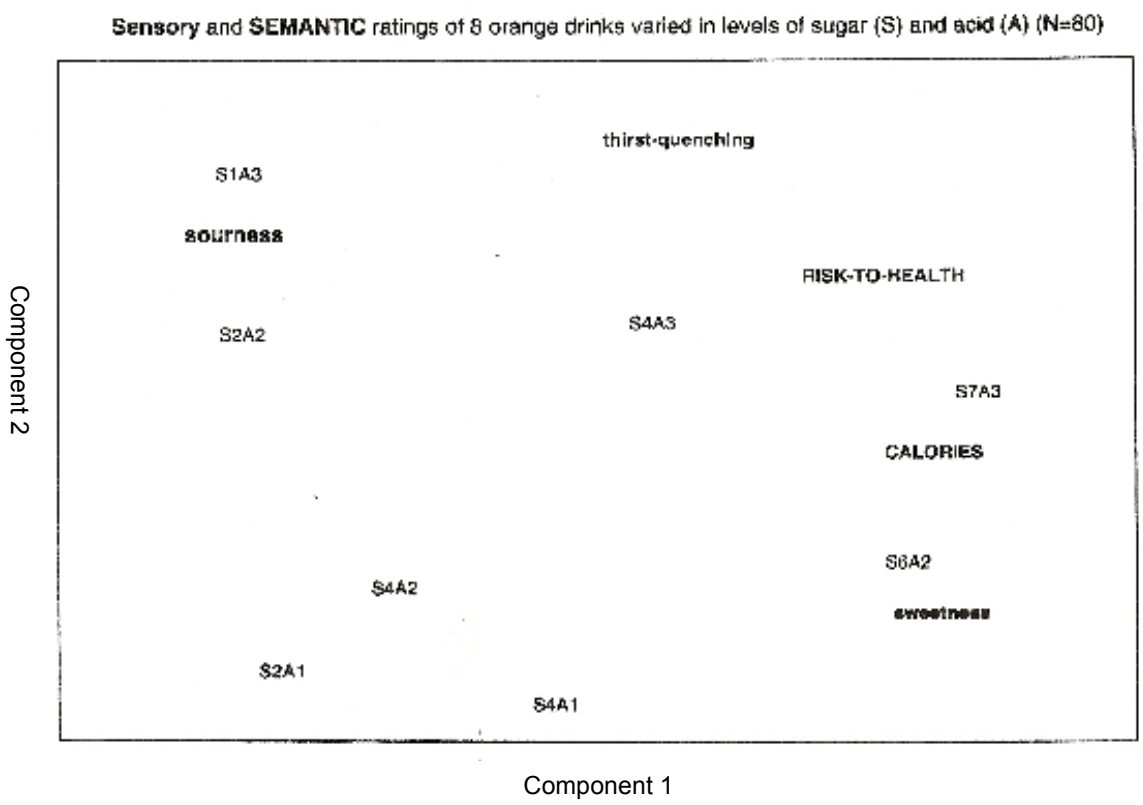
For example, multidimensional scaling applies indifferently to "sensory" and "general knowledge" categories as Medin and Barsalou called them in Steven Harnad's book "Categorical Perception." That may be because MDS is 'non-metric' and so side-steps the problems of scaling within and across material and symbolic parameters. This talk introduces a way of scaling all sensed material features and attributed semantic features on the same unit, thereby allowing measurement of causal interactions between the processes transmitting information through the mind about features of all types.

First though, for comparison, let's consider an example of the use of MDS to include semantic and sensory descriptors within one statistical model.

The data were collected from a consumer panel of 80 individuals who assessed eight orange-flavoured drinks that were varied in levels of sucrose (table sugar) and citric acid, a major sour component of oranges. The two largest components from MDS of the whole panel's data are plotted in the graph below (over the page).

This statistical consensus model placed the drinks in positions relative to the descriptors "sour" and "sweet" that are appropriate to their contents of sugar and acid. The sample (S1A3) that was highest in acid (level coded "A3") and lowest in sugar ("S1") is closest to **sourness** and is far from the samples tested that were highest in sugar (S7A3) or lowest in acid (S2A1) on both the vertical and horizontal components of the MDS solution.

This psychometric space successfully accommodated both the sensory concepts 'sour' and 'sweet' and the semantically more complex concepts 'risk to health' and 'calories.' Furthermore, the semantic category, 'calories' is close to the sensory category, sweetness (see bottom right of plot, over the page), as well as to the concept of risk to health, presumably from the high sugar level (S6) to which strong sweetness is attributed.

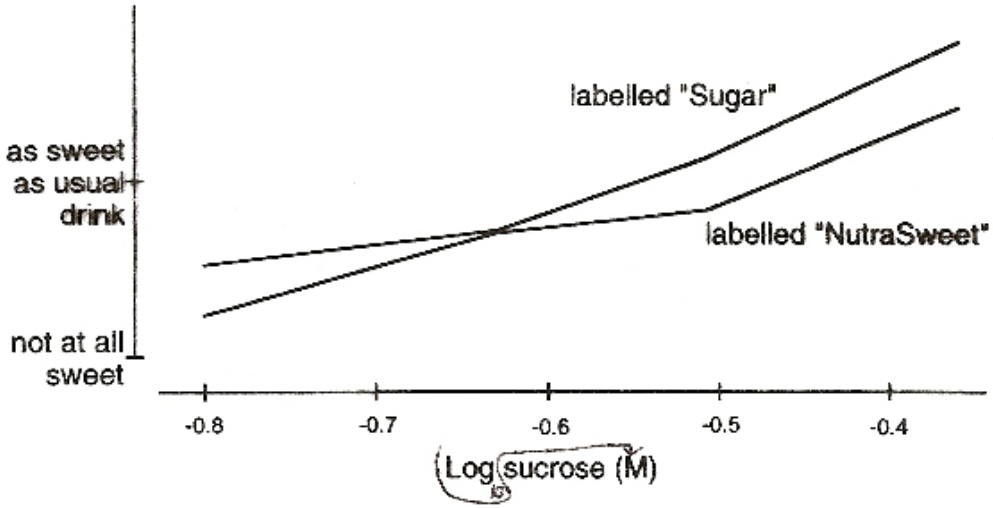


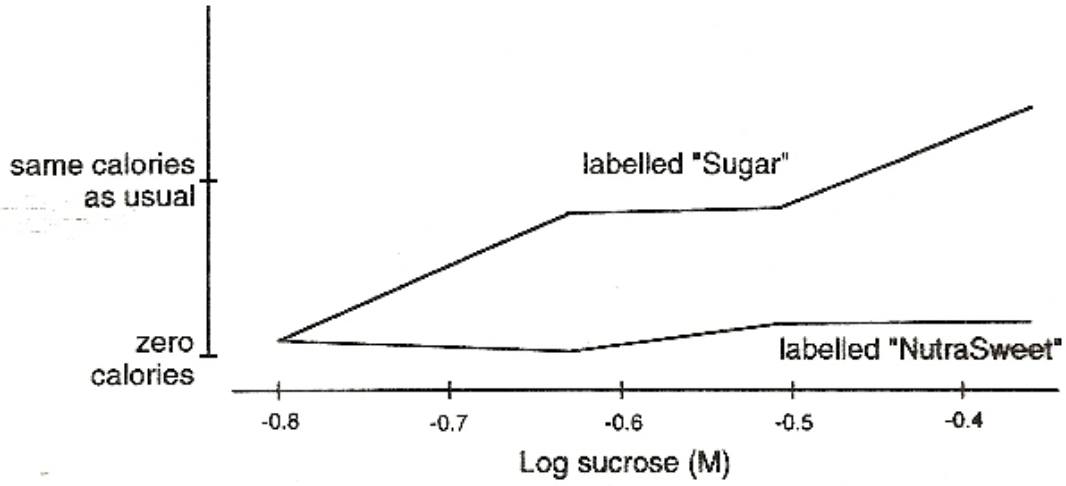
This statistical patterning of responses, however, is ambiguous as to the status of a category, between sensory and semantic. This is evident from the placing of the ratings of the drinks for "thirst quenching" (at the top of the plot, above). Arguably this is the appropriate position for the sensory category of an orange-like balance between moderately strong sweetness and considerable sourness. However, equally, the position could represent 'general knowledge' from experiences of thirst being quenched by oranges or orange juice that taste strongly. The psychophysical approach to which we now turn can resolve such ambiguities

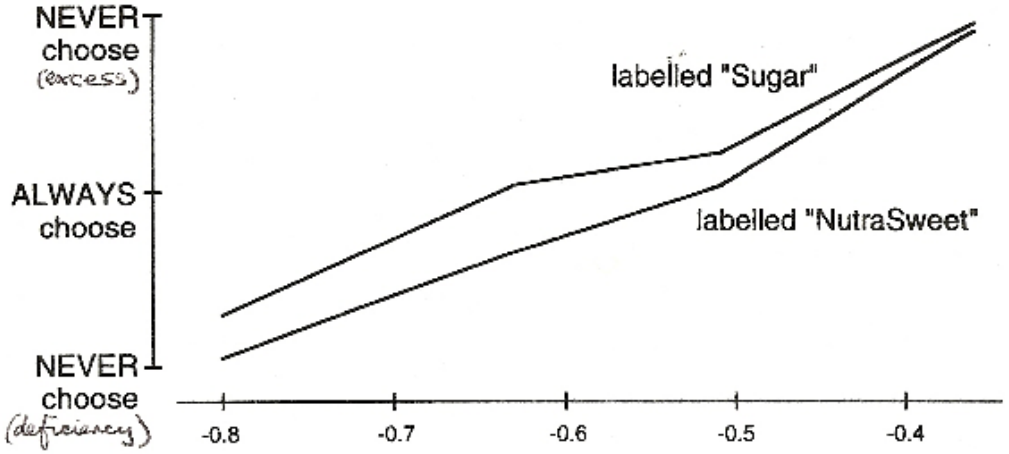
We used the same orange-flavoured drink in our first attempts to use discriminal integration psychophysics to measure interactions between sensory and semantic features. The sensory feature was the taste of a sweetener (table sugar). The semantic feature was verbal information symbolising the energy contents of sweeteners used in drinks.

The design is illustrated by the raw data (next page) from one of the 145 assessors who were familiar with this drink on vending machines. Two factors were varied independently among eight samples of the drink presented to each assessor. The sensory factor was the concentration of sugar in the sample (on the horizontal axis of each graph, in the equal-ratio scaling of log molarity). The semantic factor was the calories implied by a label alongside each sample.

The label (stated beside each line of data) was either “Sugar” or “NutraSweet,”







described as “a low-calorie sweetener” (as on the jars of the powder). As you can see from the graphs, each label was presented on drinks with the same four levels of sucrose, the only sweetener used in this experiment.

The assessors had to make three quantitative judgments on each drink.

First, they rated the sweetness of the sample relative to the sweetness of their usual orange drink, by marking a point on a horizontal line similar to the vertical axis in the uppermost graph on the previous page.

Next, they estimated the relative energy content of the sample drink, using a horizontal version of the vertical axis in the middle graph above.

Immediately we can see an advantage of a psychophysical approach over a psychomteric approach from the upper two graphs. Sweetness and calories were not differentiated by the MDS model shown at the start of the talk. Yet sweetness and calories gave very different pairs of psychophysical functions, showing very strongly the expected effect of the contrast in semantics between the word “sugar” and the brand name of an artificial sweetener.

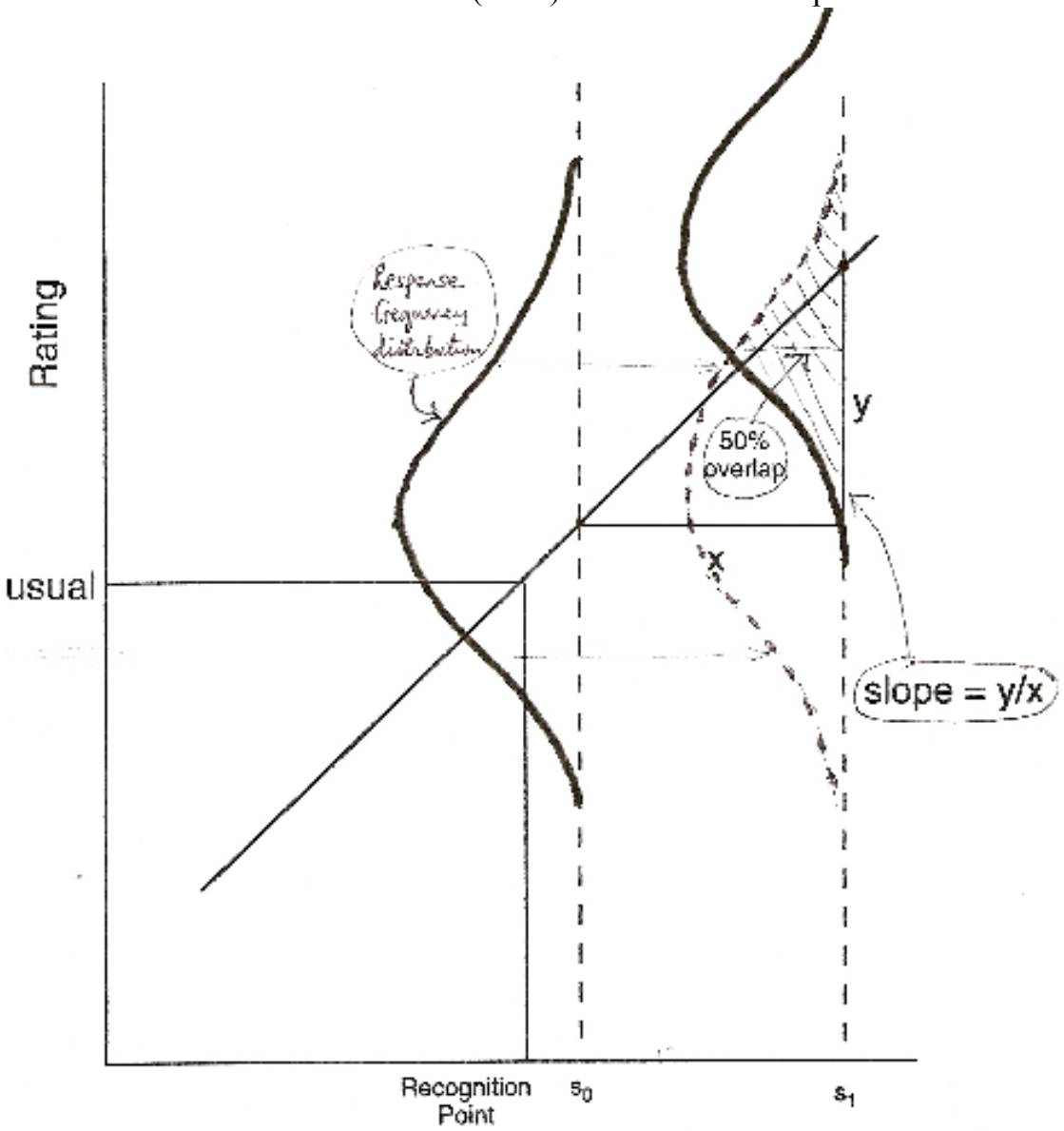
Finally, the assessors rated their disposition to choose each particular drink, from “ALWAYS” to “NEVER.” These ratings can be ‘unfolded’ (Coombs, 1964), as shown in the graph at the bottom above, by differentiating too much sugar from too little sugar. This produces a monotonic relationship between levels of sugar and ratings of preference, rather than an inverted V.

This individual’s data are interpretable in quite a complex way by comparing the shapes of the six psychophysical functions. Reading horizontally across the data in the bottom graph on the previous page, the ideal level of sweetness (provided by sucrose) was considerably higher when the taste was attributed to the low-calorie sweetener than when it was attributed to ‘full calories’ sugar. Only a dislike of sweetness perceived to be much greater than usual (top graph) suppressed this liking for sweetness (right-hand end of bottom graph) when the drink was believed to be free of calories (middle graph). Clearly, if we could measure cognitive interactions among the psychophysical functions, such interpretation might be made much more securely.

Therefore we’ll spend the rest of this talk explaining how we measure sensory-semantic interactions using the data from another assessor, one who professed always to use “diet drinks.”

The key innovation is to scale both sensory and semantic stimuli on the same metric, using the traditional measure of discrimination performance, known in subjectivist terminology as the “just-noticeable difference” (JND). Instead of assuming that the descriptive ratings measure differences in strength of private sensations, we rely only on the objective fact that they are sensitive to disparities in quantity in the presented stimuli, be it material or symbolic. More deta are needed to address the question whether this objective discrimination is achieved phenomenologically, verbally, neurally or by some other mode of processing: we tackle such issues after we have measured the discriminative

performance of each of the six response-stimulus relationships, using the conventional Case V of Thurstone (1927) for a "discriminal process."

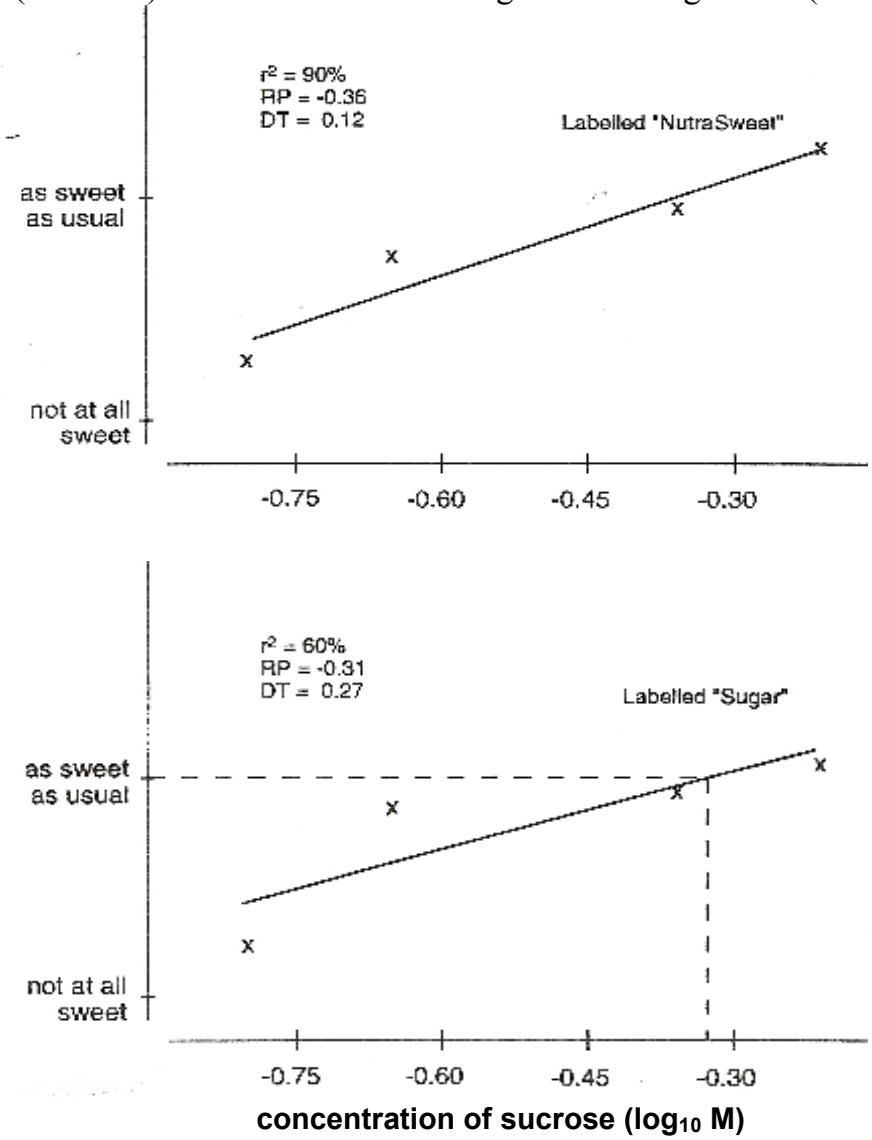


Just as in the estimation of a JND, what we call the half-discriminated disparity (HDD) in levels of a stimulus, between s0 and s1 in the graph above, is at 50% overlap between the probability distributions of the responses at each level, estimated from the mean square error of least-squares linear regression through the raw data from an individual within a session. That is, the 75% quantile of the estimated distribution of responses to the lower level of stimulus are superposed on the 25% quantile for the higher level. (The graph as drawn above does not have enough overlap.) Thus the formula for the HDD (JND) is the square root of the mean square error around the regression line divided by the line's slope, multiplied by twice the z value for 25% (0.675)

The assumptions of linearity and constant residual variance are testable on data (and have held up well over many experiments in our lab.).

As long as least-squares linear regression computes, very few data are needed to estimate an HDD, and also to interpolate a value for the 'norm' of that stimulus for that person in that session – whatever is the implicit usual value, ideal point or 'template' that the ratings were anchored on by the assessor in that context. Of course, both estimates go down in reliability with smaller numbers of data. Nevertheless, the orderliness of merely four data-pairs, as in this experiment, can be monitored as variance the regression accounts for.

This assessor's sugar-sweetness functions for "NutraSweet"-labelled drinks and "Sugar" drinks are given below. Unsurprisingly for a user of Diet drinks, the function is more reliable for the samples believed to be low in calories ($r^2 = 0.90$) than for the declared sugar-containing drinks ($r^2 = 0.60$).

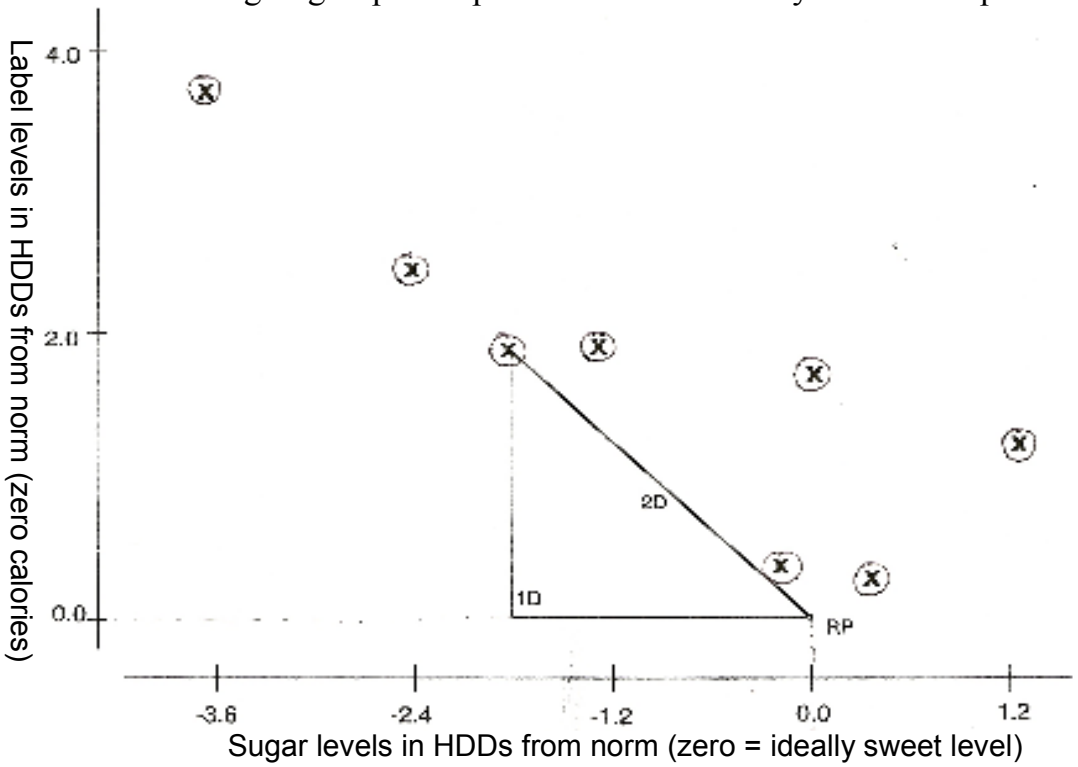


The recognition points (RP), i.e. the norms for "usual sweetness," were similar for the two labels. The slope was lower for "sugar"-labelled samples as well as the MSE being larger (smaller r^2) and so the HDD was considerably worse (higher). "DT" (discrimination threshold) in the graphs is the Weber Fraction (HDD - 1). This HDD of 1.12 is close to the limit for sugars in water and so this person's sucrose discrimination performance by normed sweetness ratings appears to be very good with the desired low-calorie sweetener label, albeit subject to the wide confidence limits on regression through only four data.

Exactly the same calculations were performed on the sweetener calories feature. Two unquantified levels of a category can be discriminally scaled but in this case the "low-calorie sweetener" brand is declared on the jar to have an energy content 10% that of sugar (100%) and so a quantitative function was calculated for the two levels of caloric label.

We can now scale the stimulus values for each of these sweetness functions (and the calories and choice function) in units of HDDs from norm (RP). Each function is a piece of evidence on the causal processes in the mind of the assessor during the session, i.e. the cognitive mechanisms of the decisions made on sweetness, calories and likelihood of choice. Fine discrimination by a rating is the same thing as strong control of the rating by the stimulus.

We can now produce the psychophysical advance on the psychometric modelling illustrated at the start. This time the two-way graph visualises determinate formulae for a person's interacting mental mechanisms, instead of the statistical fitting of grouped responses into a minimally stressed map.

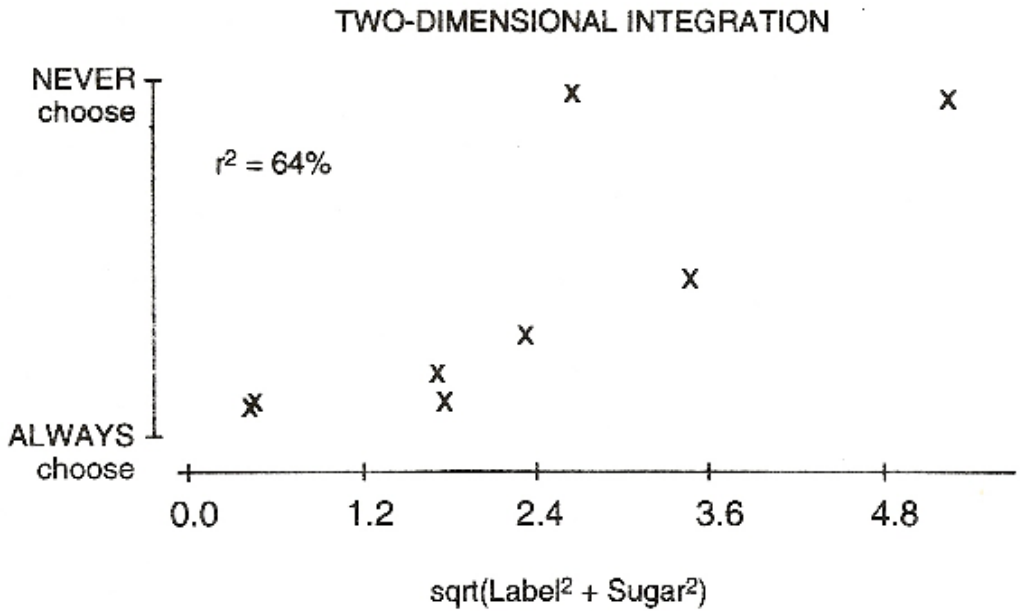


Each point (**x**) on this HDD-scaled graph of the two stimulus features (looking down on the base of a cone from its apex) is a sample of the drink as perceived by the assessor's ratings of sweetness (x axis) or calories (z axis). The plot shows that all the samples were too calorific for this diet drink user, although two only slightly so (labelled "NutraSweet"). One of the samples was definitely too sweet (~1.2 HDDs above ideal, or recognition point, RP), while three samples were far from sweet enough (>>1 HDD below ideal).

The right-angled triangle drawn on this stimulus graph shows two possible sorts of interaction between the distances of sugar levels and calorie levels from ideal. If the taste of sugar and the meaning of "calories" combine as two distinct features, the distance in HDDs of a sample from the joint ideal point (0, 0) is the length of the hypotenuse of that triangle (2D on the graph). If, on the other hand, preference (say) treats sweetness and calories as the same, the combination puts the two distances end-to-end, i.e. adds them together (1D).

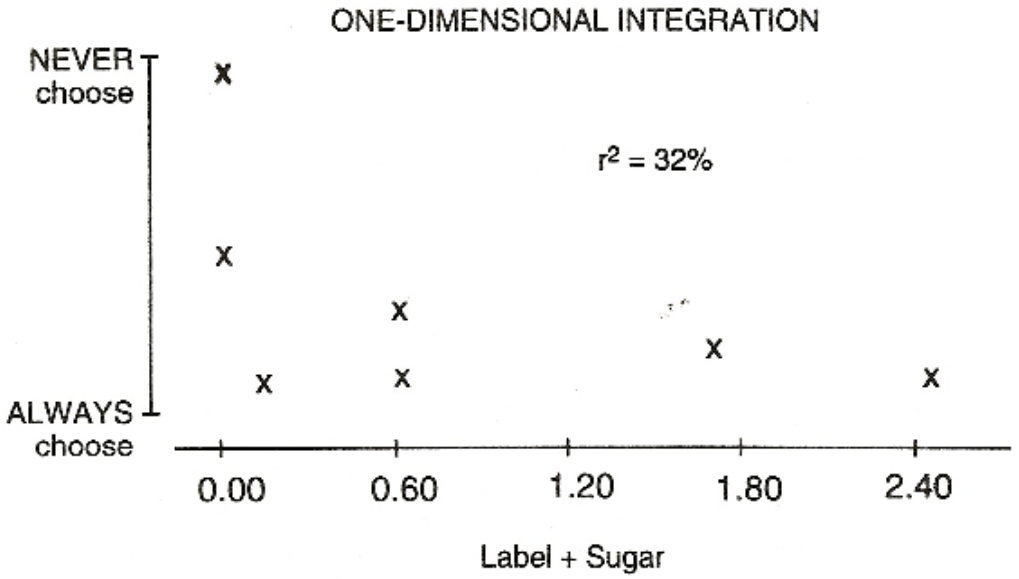
Note that the signs of HDDs from norm are retained in 1D models and so the sum may be a subtraction and can give a positive or negative value, whereas 2D models are unsigned (or always positive) because values are squared before summing and then taking the square root in accord with Pythagoras's Theorem.

Two-dimensional integration gives a moderately good account of this diet-drink user's choice ratings (scatterplot below), with $r^2 = 0.64$.



In contrast, output from 1D modelling (on the next page) is effectively nonsensical, forming an L-shaped function with a slope largely attributable to a single sample of the drink and accounting for only a third of the variance.

Hence in this person, the sweet taste and the calorie label are perceptually distinct – and indeed could be sensory and semantic features respectively. Hence, discrimination psychophysics resolves the cognitive processes in choice,



whereas psychometric response patterning puts sweetness and calories close together in both of the first two components (see the first graph in this talk).

Obviously, more than three sets of eight data-pairs are needed to draw reliable conclusions about an individual in a situation. We are pursuing issues of replication within individuals. Nevetheless, we can test for reliability to some extent by looking for systematic effects across independently characterised assessors within this first experiment by itself.

The amount of variance in rated choice accounted for by 2D and 1D models showed a reliable difference between diet-drink users and sugar-drink users. In two-way ANOVA, 2D did better than 1D ($p < 0.05$) but there was no reliable difference between the two sorts of habit. The interesting result was a reliable interaction effect ($p < 0.05$), with 2D accounting for more variance in preference than 1D in users of low-calorie drinks and the other way round in users of sugar drinks. The data need examining more closely but there is a fairly straightforward interpretation of this contrast between the groups.

The users of diet drinks are personally very familiar with 'uncoupling' of sweetness and calories: the taste is a sensed material characteristic but the construct of calories is the key part of a highly salient belief about a drink. Hence the '2D' decision-making processes evident in the one assessor above may be quite common among users of low-calorie drinks.

In contrast, those who habitually opt for sugar-containing drinks may treat sweetness as meaning the same thing as the (high) calorie label – a symbol conveying the amount of energy in the drink which they desire, maybe to kill off hunger or to boost "energy" in the sense of bodily and/or mental vigour.

To conclude, the new approach starts with complete analysis of the data from each individual and postpones the modelling of the group (and subgroups) until that can be done on the performance characteristics of the individuals. In

MDS, individuals can be plotted as vectors. Nevertheless the model forces a consensus across the panel in the first few components. More to the point, that approach is incapable of measuring what is going on in each individual's mind.

Also the new approach uses all of the data, not just response values but stimulus values as well. That is, the approach is psychophysical, operating on manifest variables to derive evidence of underlying causation, in contrast to psychometrics that models patterns in the responses and is content to recover information about stimuli as latent variables and data-structures of origins that are unspecified from data.

Finally, this approach is mathematically fully determinate, with no loose parameters. Even the estimation of each elemental psychophysical function from the raw data from an individual in a session by a least-squares statistic is in fact algebraically determinate. This all contrasts with MDS and other psychometric modelling that improve the fit to data by varying weights etc.

Annotated Bibliography (April 2010)

The theory generalising normed discrimination scaling to multiple features was published in the same year as these talks. The extensions from multisensory integration to multiconceptual and sensory-conceptual interactions were also made in that paper.

Booth, D.A., & Freeman, R.P.J. (1993). Discriminative feature integration by individuals. *Acta Psychologica* 84, 1-16

The full analysis in accord with Booth and Freeman (1993) that was made at the time of the data from the second experiment on orange drink above has now been published in brief.

Freeman, R.P.J., & Booth, D.A. (2010). Users of 'diet' drinks who think that sweetness is calories. *Appetite* 55, in press.

'[Scientific] Postscript'

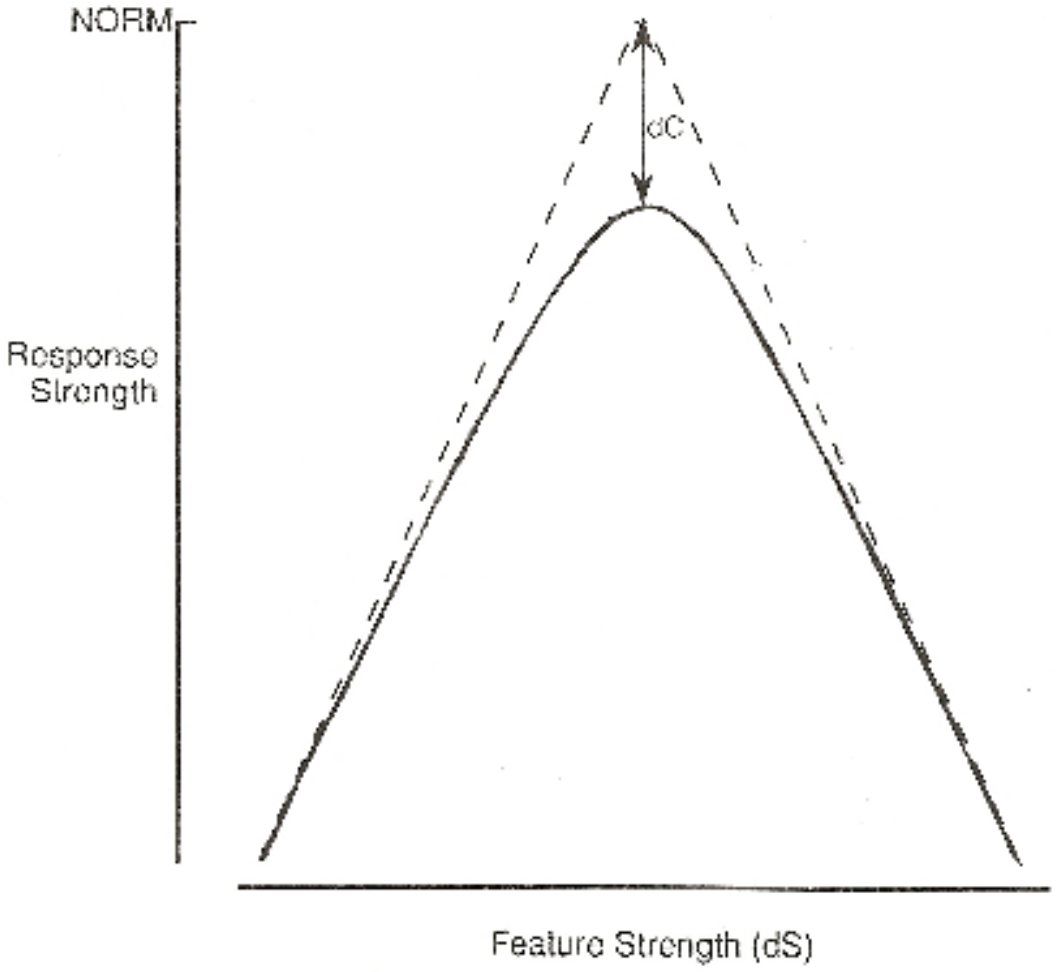
The graph above of two stimulus features (on x and z axes) was described as a view down from the apex of a cone onto its base. The vertical dimension of that cone (the y axis) is the response that is cognitively integrated from the two features. Pythagoras's Theorem generalises to any number of dimensions and so the theory includes an unvisualisable 'hypercone' involving three or more stimulus features (Booth & Freeman, 1993).

The same theory of multiple-featured objects and situations improves on the linear unfolding of choice ratings and other responses peaked on levels of the stimulus, used above and in normed discriminal scaling of a single sensory feature in a familiar context by Mark Conner with David Booth, from which the Booth/Freeman approach was generalised.

Observed data are theoretically on the surface of the cone at a vertical cut parallel to the axis of the stimulus being varied. If this is the x axis, then the z axis can be considered to be an integrated stimulus of all the other features in the familiar context. When the assessed sample is perfect in all respects except the varied feature, then the data fall on the isosceles triangle through the apex of

the cone. When however there is some 'defect' in the context (such as a water-clear or red-coloured orange-flavoured drink), then the vertical cut is some way from zero on the z axis and the data fall on a conic section (right hyperbola) – as in the graph below.

(This quantitative theory of 'contextual defects' in data on sensory acceptance was presented in a plenary session of the first Pangborn Symposium, held in Finland in August 1992.)



A contextual defect in integrative ratings (y axis) of a single feature (x axis) with the joint norm being at zero on the z axis (going into and out of the page).

dS: discrimination-scaled levels of the varied feature, S.

dC: contextual defect measured in units of strength of response.

The intersection of the horizontal tangent of the peak of the conic section (continuous line) with the bounding isosceles triangle (broken line) measures the contextual defect in stimulus units, i.e. in HDDs from Norm.

(Figure from Booth & Freeman, 1993)

Talk 2 at CSBBCS/EPS

SUB-, PER- AND CONCEIVING: FEATURE-DISCRIMINATION CHANNELS IN INDIVIDUALS' INTEGRAL AND ANALYTICAL RECOGNITION.

D.A. Booth, R.P.J. Freeman* and M.T. Conner**, *School of Psychology, University of Birmingham, Birmingham B15 2TT, UK, and **Dept. of Psychology, University of Leeds, Leeds, LS2 9JT, UK*

One criterion of preconscious perceptual performance that we suggested in the mid-1980's was that integral responses had greater differential acuity for a feature that had analytical responses, e.g. the taste of caffeine in coffee controlling preference ratings more effectively than it did bitterness ratings. We have now generalised this measurement of the convergence of difference-signals to a diagnostic of feature-integration level, as subceptual ("straight through"), perceptual ("sensory") or conceptual ("semantic"). The sizes of two or more hypothetically salient features are varied independently of each other within ranges recognisably close to a familiar situation. A graded response sensitive to variations in size and character of a combination of the features (integral) and responses relatively specific to each feature (descriptive) are collected. Differently JND-scaled distances of each feature in the test situations from that feature's level in the familiar case are then combined through distinct or identical channels to predict the integral response. If the most predictive integration model uses feature JNDs estimated from the psychophysical function for the integral response, this indicates preconscious processing. If JNDs from descriptive functions yield the best predictions, this indicates that the integral responding is sensation or percept based. If acuity of descriptive responses for the integral response yields the best model, then the integration is presumably more reliant on attribution from the meaning of the descriptive concept. This diagnostic will be illustrated from complex tastes, feels and smells of foodstuffs.

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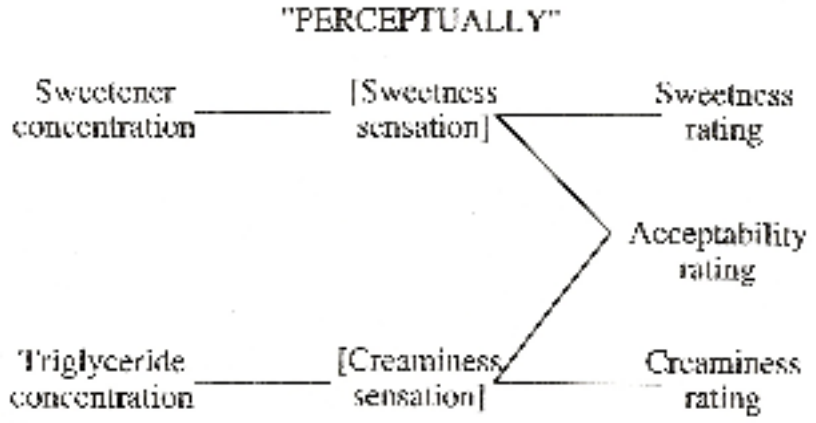
Cognitive processes of recognising an object by two of its features
e.g., personal acceptance norms (ideal points) for the levels of sugar and of cream in an ice-cream or in a cup of sweet milky coffee

A person's overall liking for an ice-cream or a cup of sweet milky coffee may be based on awareness (sensations) of its sweetness and creaminess.

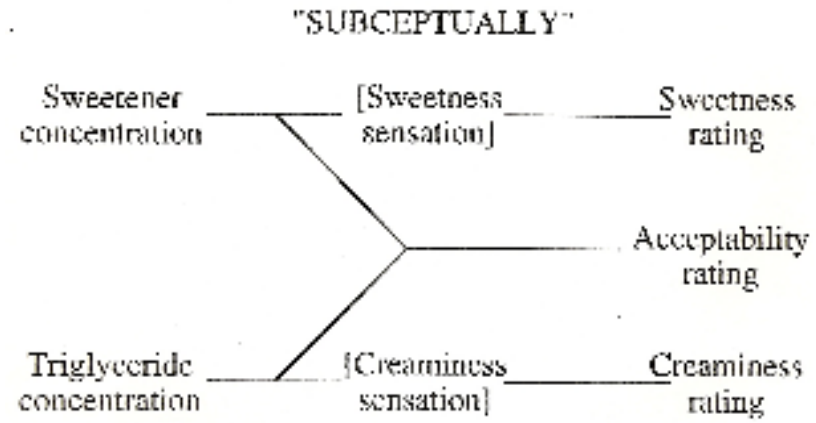
In this talk, we call that sort of mental processing "PERceiving."

Here is a diagram of the information-transforming channels involved. Note that the integrative decisions come after the states of experiencing.



Sometimes, instead, the decision to accept the ice-cream or the coffee might be under "straight-through" control by stimulation of the senses by the levels of sugar and of cream (Booth, Conner & Marie, 1987).

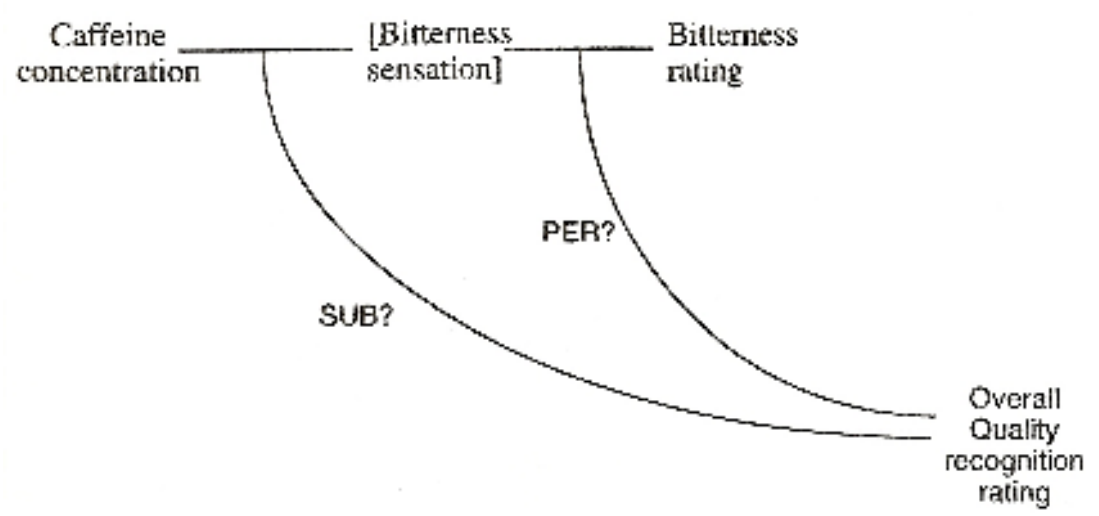
That is, these two sources of stimulation may be integrated preattentively or subconsciously. Here we call that sort of achievement "SUBceiving."



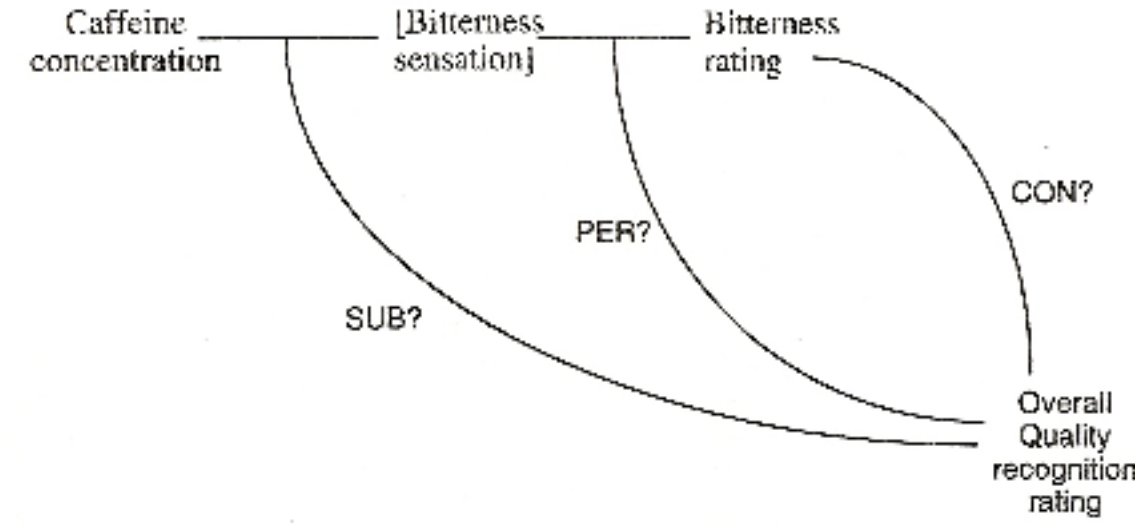
In this case, the integrative decision pathway operates without going through either of the two states of subjective experiencing.

Those two diagrams can be superposed, to put the alternative pathways (channels) onto one graph. Also just one of the features can be considered, albeit still within its context of the whole sensed object (and situation).

Changing the example from the sugar and cream in the coffee to the bitterness of its caffeine content, either a SUBceptual process or a PERceptual process might influence the acceptance of a cup of a particular coffee, or a recognition of how good in quality that sample of coffee was:-



Thirdly, the verbal concept of bitterness of taste might by itself drive the recognition of quality (or the ideal level of caffeine for that drink of coffee) – a CONceptual process. Adding that third possible information-transmitting channel to the combined diagram, we get:-



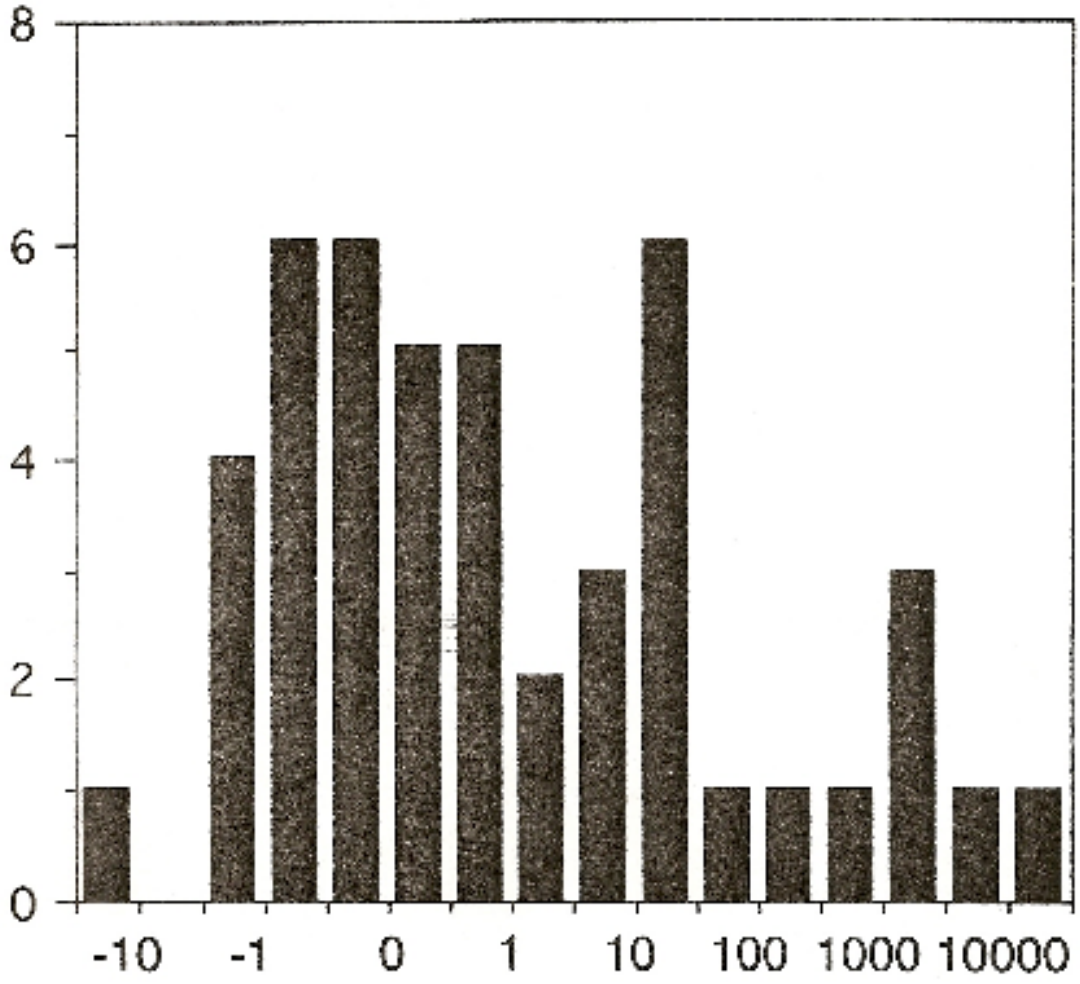
Booth, Conner and Gibson (1989) found that subceptual discrimination between levels of caffeine was quite common in preferences among coffees.

Each assessor's Weber-Fechner ratio (JND, HDD) for discrimination between caffeine levels was calculated from ratings of bitterness or acceptance and the concentration of caffeine as described in the previous talk.

In about half the people tested on their usual drink of coffee, the ratio was much higher for bitterness than for preference – above the normal distribution that was seen around a (log) ratio of zero, from about 1/10 to 10/1 or so.

Number of people at each difference between the ratios is given below.

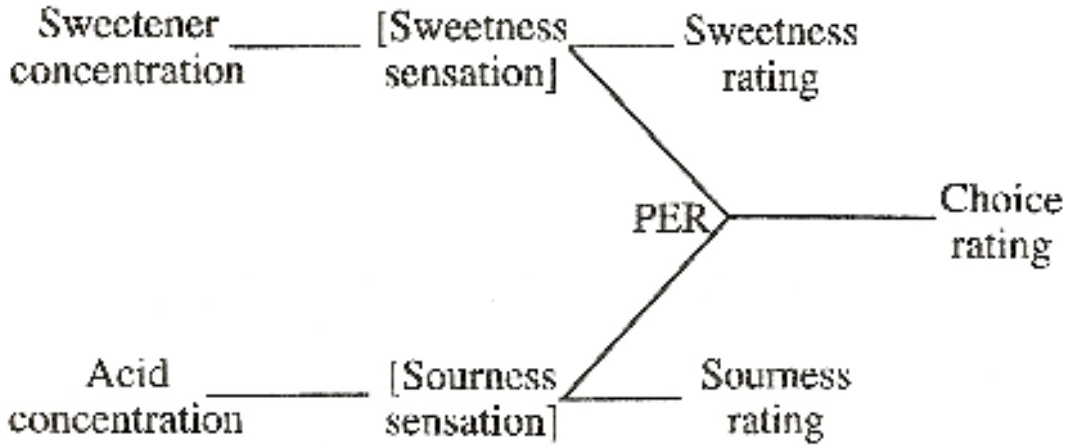
Bitterness *minus* Preference DRs

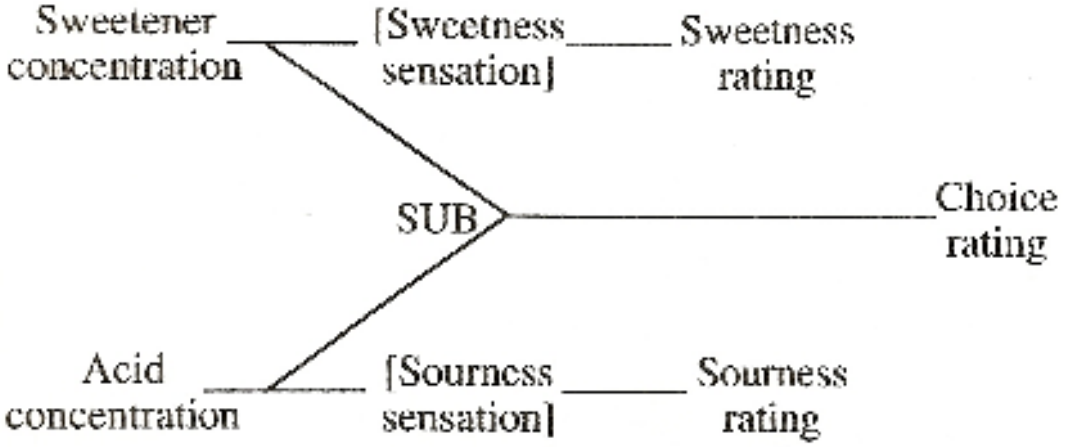


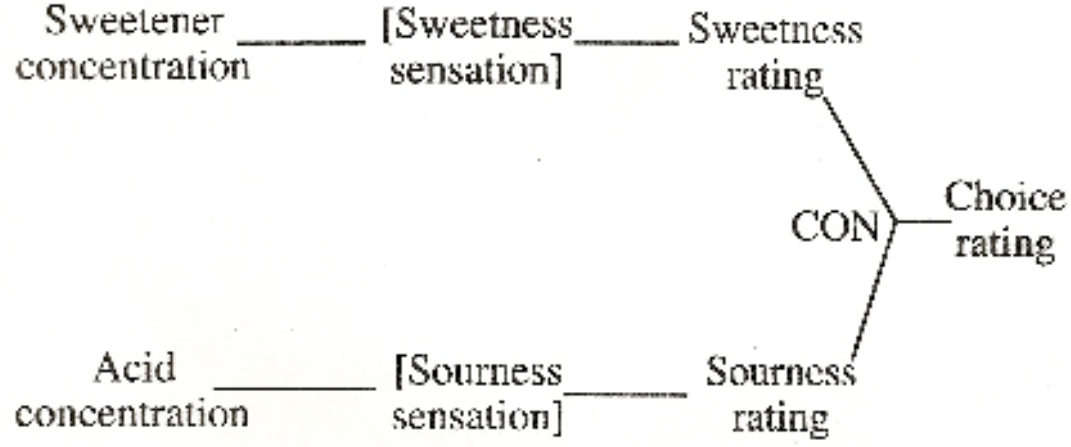
Discrimination ratio (DR) for bitterness *minus* DR for preference (logarithmic scale)

That illustrates a use of the 'unit' of discrimination to analyse recognition of a single feature. We now turn to two features, sufficient to illusrate the approach to interactions among any number of features.

Below are the causal diagrams of the three types of cognitive processing considered in this talk, for the case of two tastes in a fruit drink.







I (RPJF) have programmed a modelling shell that tests SUB-, PER- and CON-ceiving against each other on each set of data from one assessor in a session of ratings of sample items of the food material. As well as using this multisensory approach myself in work focused on tastes (Freeman et al., 1993), it is being applied within two other sensory modalities.

Martin Kendal-Reed has been analysing the integration of familiar smells from mixtures of odorants, on a grant to David Booth from UK SERC Biology.

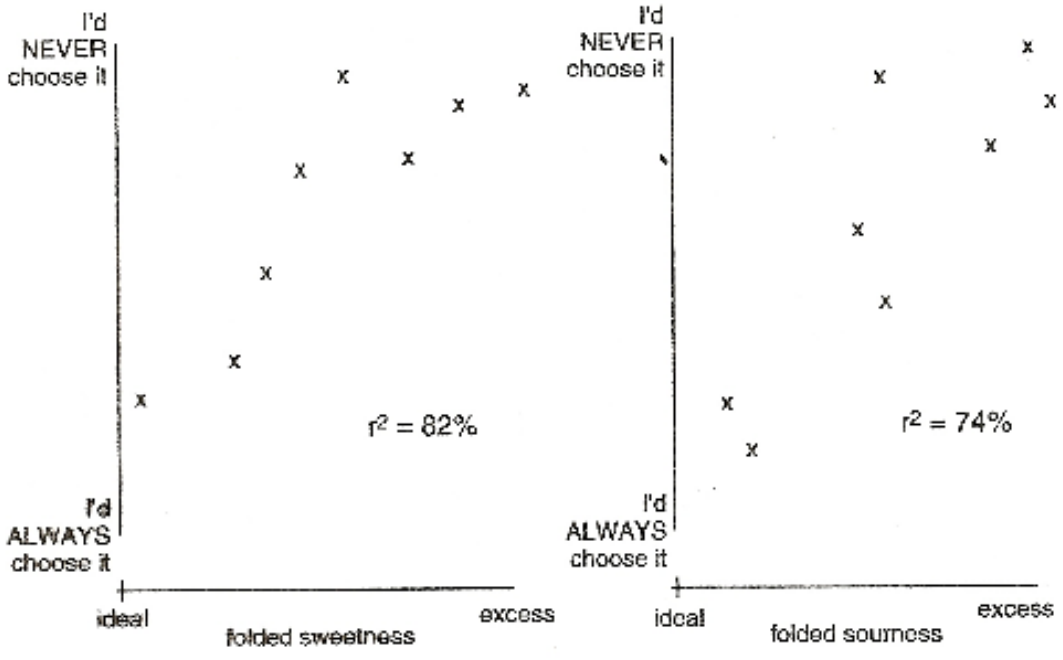
Nicola Richardson did her PhD with David on the tactile aspects of the creaminess of milk in the mouth (which has a strong olfactory component too). We are testing the types of processing by which mechanoreceptor stimulation patterns from the fat globules and the concepts of 'thick' and 'smooth' are integrated into recognition of the amount of fat in a dairy product (Richardson & Booth, 1993).

So the rest of this talk I'm giving for David illustrates details of each of these three types of processing by different indiviuals when assessing a familiar material containing mixtures varying in the levels of sucrose and citric acid.

Let's start with preferences (ratings of disposition to choose) driven by the concepts of 'sweet' and 'sour' - that is to say, an assessor in whom conceptual processing provides the best account of choice.

The raw data for eight drink samples are given in the two graphs below.

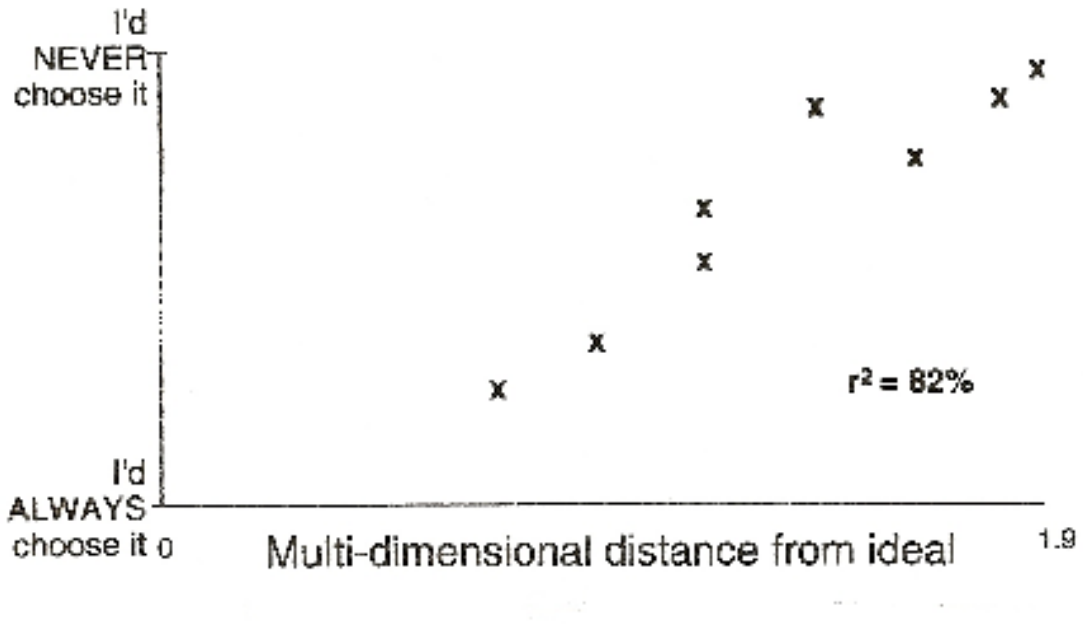
CONceptual individual



The ratings of sweetness and sourness of each sample of the orange drink were from ideal to excessively strong or weak. In the above plots, each of those two sets of scores is 'folded,' superposing the two extremes. In regression onto always/never choose ratings (folded already by the assessor), a large majority of the variance was accounted for (r^2 of 0.82 and 0.74).

After the sweetness and sourness ratings had been rescaled in number of DRs from ideal, those discrimination disatance were combined orthogonally to give the data in the graph below for the two-dimensional model - again accounting for over 80% of the variance. That was more than either the perceptual or the subceptual models accounted for in this assessor (not shown).

CONceptual individual

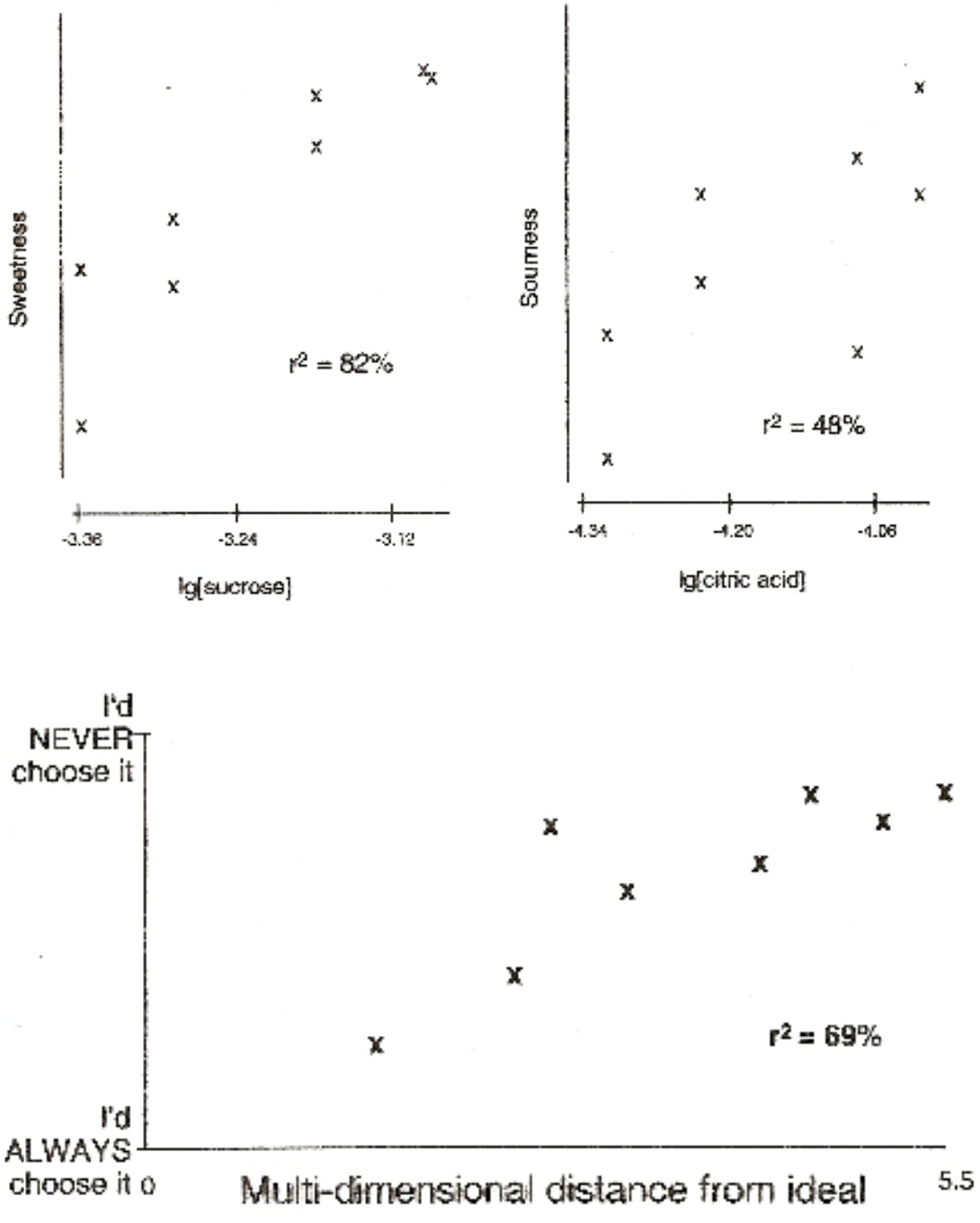


The second illustrative individual showed most evidence for a PERceptual strategy.

First the accuracy of perception, i.e. the effectiveness of the performance of description, was tested by plotting the classic psychophysical function for sweetness ratings onto ratios of sucrose concentration and for sourness onto acid ratios, in the two graphs below. Both relationships were close to linear, in accord with the generic working hypothesis, although the sourness of acid in this system was more difficult to relate to the ideal level (accounting for barely half the variance) than was the sweetness of acid ($r^2 = 0.82$). This drink is of course meant to be sweet and so the concept of sourness may be difficult to use.

The third graph over the page shows the integration into choice of those two percepts/sensations (conceptualised patterns of sensory stimulation).

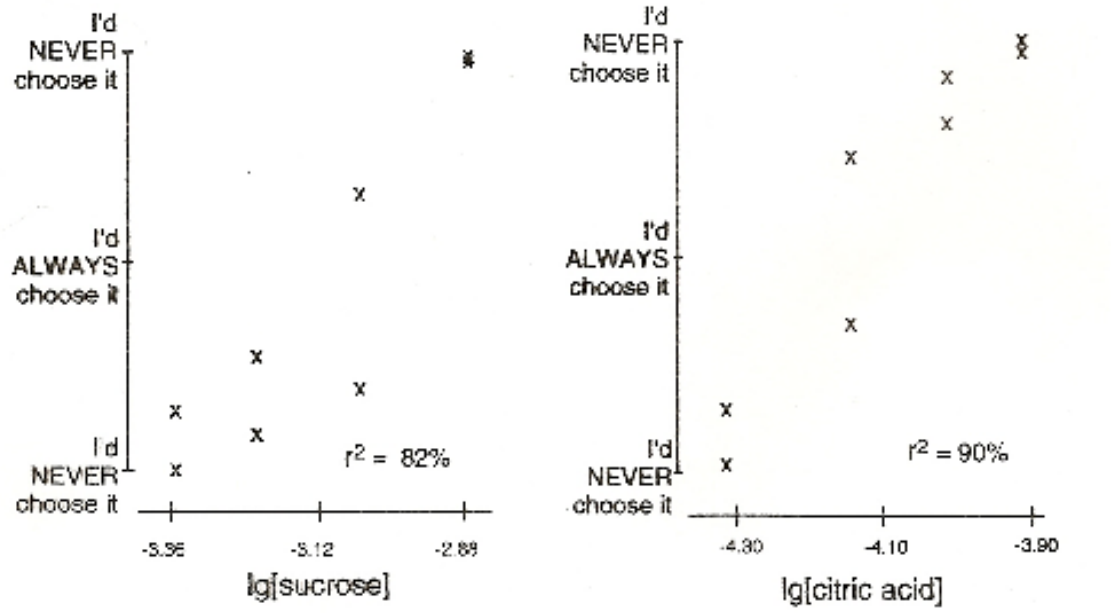
PERceptual individual



In this assessor that PERceptual 2D model accounted for more of the variance in ratings of disposition to choose ($r^2 = 0.69$) than did the 1D model or the CONceptuial and SUBceptual 2D and 1D models.

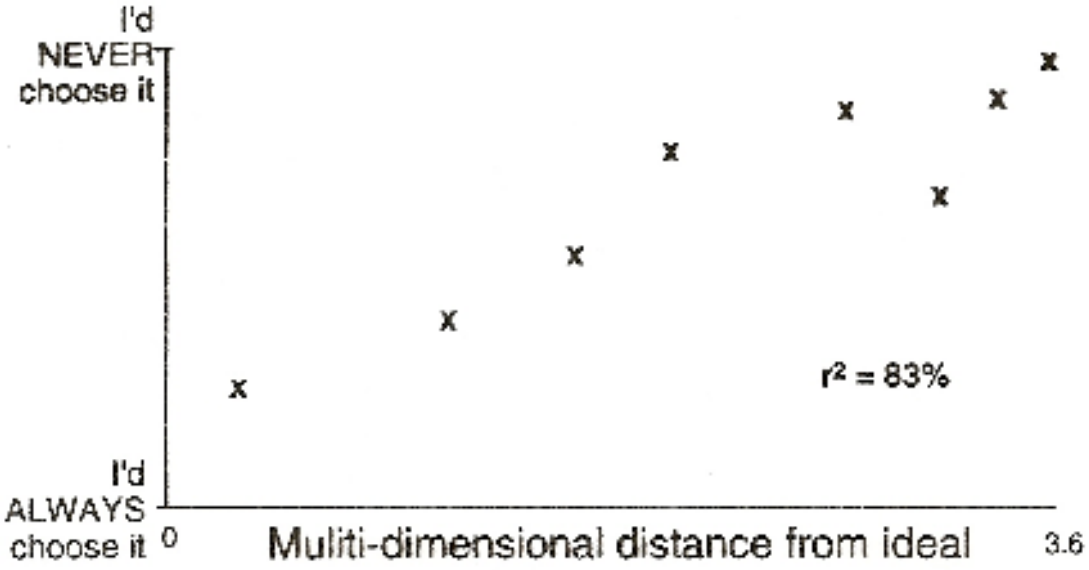
Finally, here is a person whose choices were driven directly by the stimulation of receptors for sugar and for the acid, as far as the evidence goes.

SUBceptual individual



An initial indication of strong control by the two tastants was the large proportions of variance in choice that were accounted for (r^2 = 0.82, 0.90), despite discontinuity near "ALWAYS choose" from unfolding a conic section (see the P.S. to this talk).

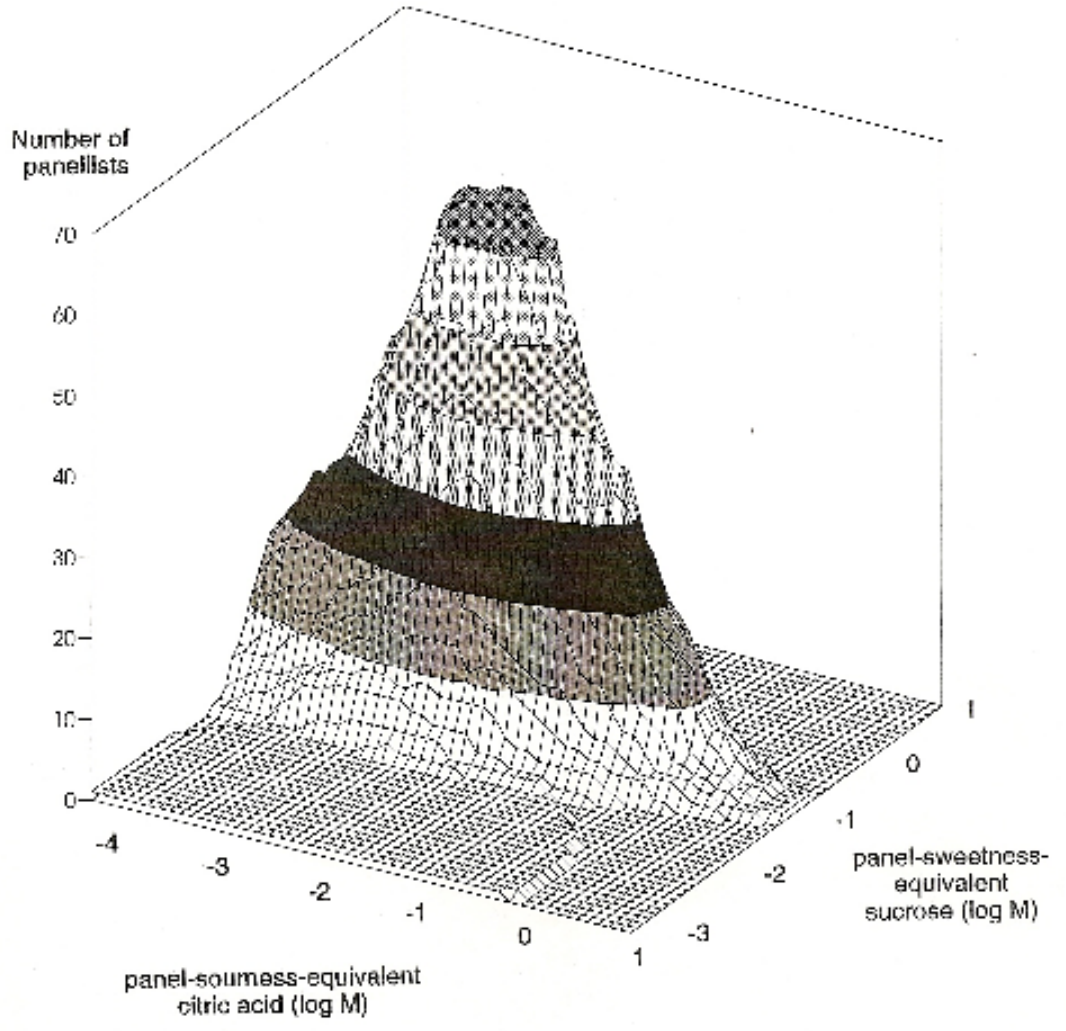
The best performing integrative model in this individual in this session was indeed SUBceptual integration of effects of the two differently sensed materials into the disposition to choose each of the eight samples of the orange drinks.



We now turn to a third way to examine the different types of processing. This is to combine the results of the individuals' analyses.

Below is a frequency polygon that aggregates the 2D CONceptual models from 80 assessors for whom all eight orange drinks were within individually preferred ranges. A person is included in this 'response surface' at stimulus values that are one HDD on either side of the ideal point (that person's 'ideal range'). The sweetness and sourness values have been converted to the sucrose and citric acid concentrations corresponding to the group mean.

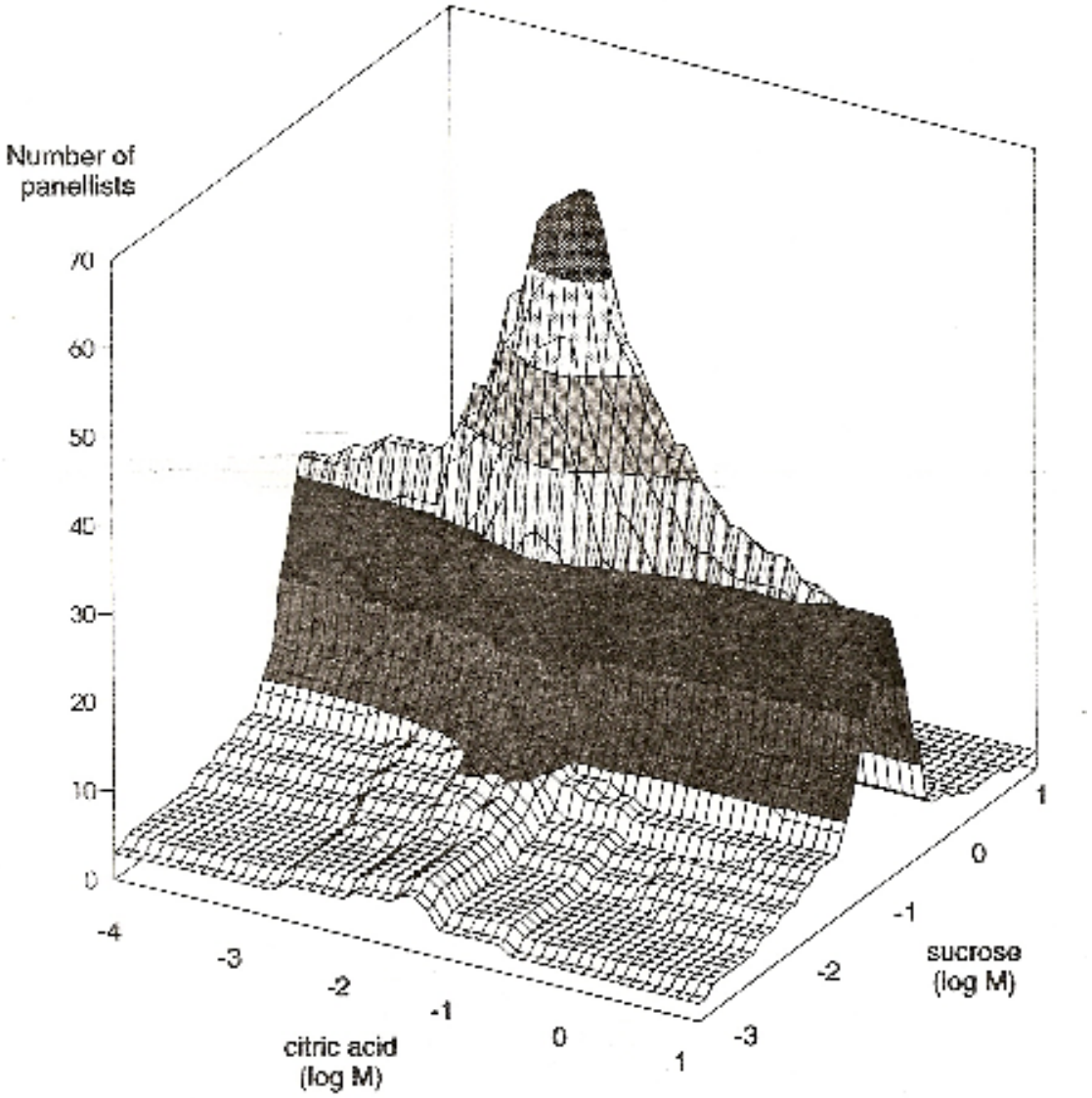
CONceptual
choice response surface



The concept 'sweet' was used much more precisely than 'sour,' presumably because assessors were acculturated to 'sweet' as relevant to a fruit-flavoured drink, unlike 'sour.' Who likes unripe fruit?

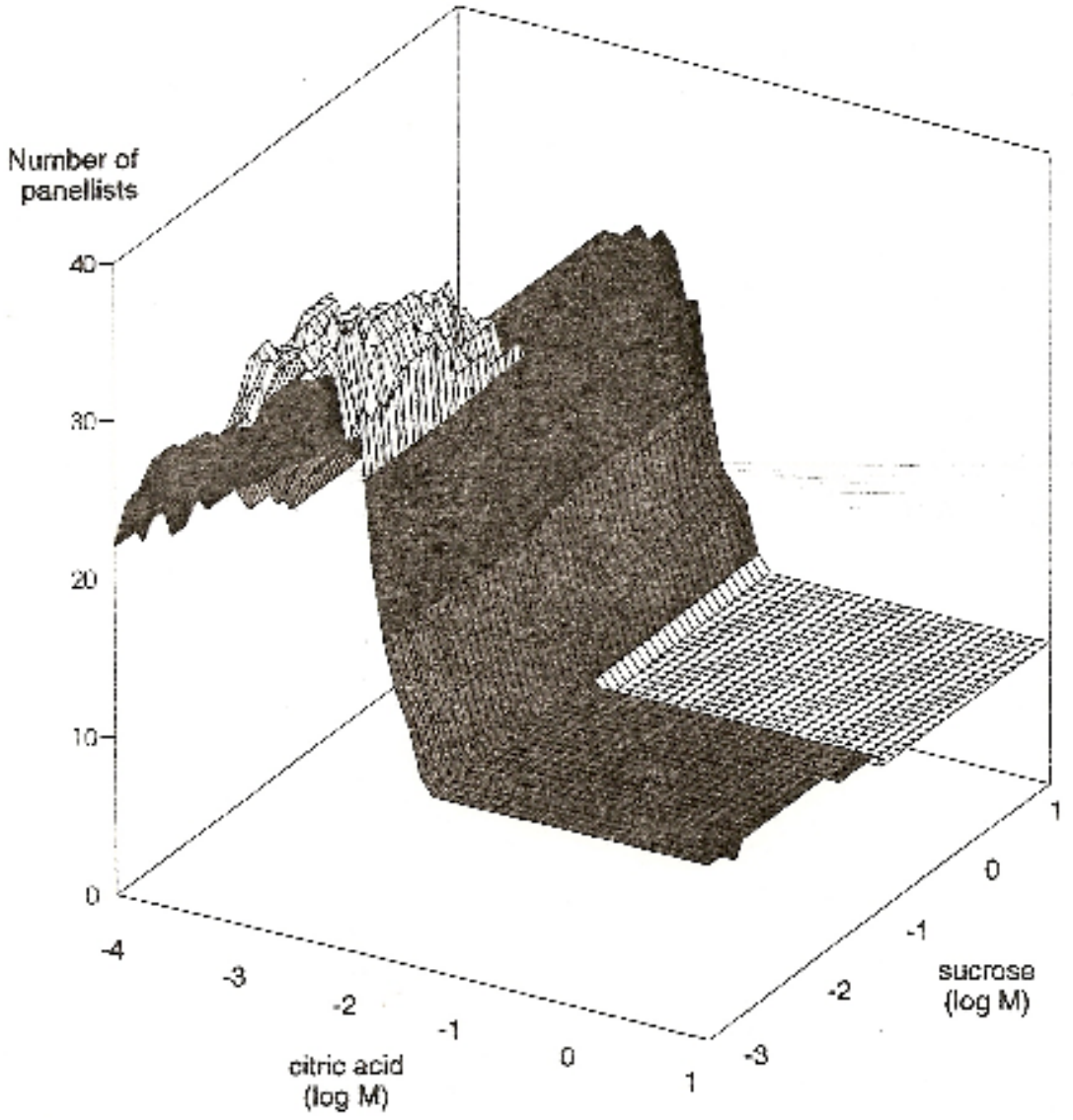
The 2D PERceptual models of these 80 assessors showed that the mental description of a tastant was also use much more precised for sweetness of sucrose than for sourness of citric acid (response surface below). About a quarter of the panellists experienced usable differences in strength of sensation of sourness (the sharp central peak) but the rest did not notice any differences at all, at least until the concentration of citric acid became very high (drop-off of the ridge above 1M).

PERceptual
choice response surface



Finally, the SUBceptual ideal ranges were aggregated (below).

SUBceptual
choice response surface



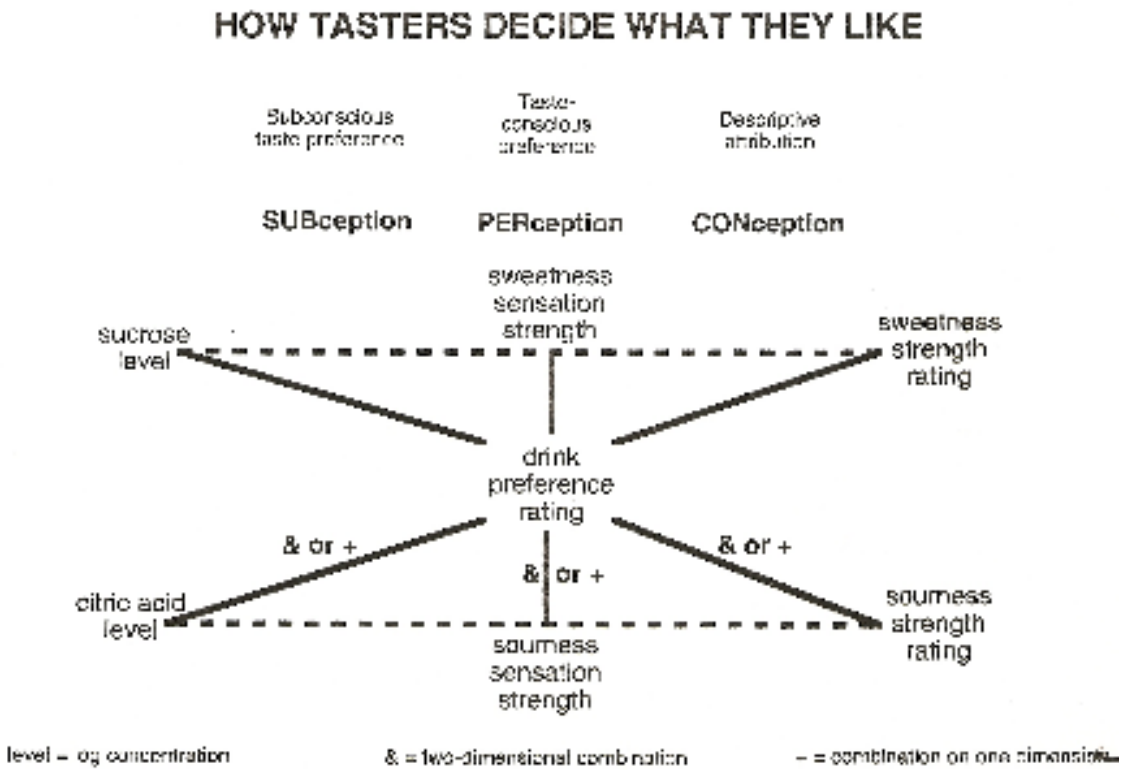
The evidence of gustatory receptors driving choice 'straight through' was dramatically different from that of conceptual or perceptual-descriptive control.

First, very few people (< 10%) discriminated concentrations of sucrose directly in their choices.

Secondly, the symmetry of ideal ranges seen for sucrose SUBception (above) and both dimensions of CONception and PERception (earlier pages) was destroyed by concentrations of citric acid that were above about 1 mM.

The low end of the ideal range for citric acid, however, followed the usual normal distribution, for half the panel anyway (far left of response surface). We speculate that the brainstem is overpowering cerebral cortex here: maybe an innately reflexive aversion to the taste of acids is breaking through the usual control by the learned construct of a balance of tastes from the acids and sugars in oranges (see the Postscript to this Talk).

So, to sum up, we have illustrated CAUSAL ANALYSIS of the mental processes that determine an individual's two ANALYTICAL responses (how "sweet" or "sour" the drink sample is – to the right of the 'cross-cross' diagram below) and one INTEGRATIVE response (how likely to "choose" – at the centre) to two independently varied material FEATURES on a familiar object.



Such a design is the minimum requirement for identifying a "hidden variable" (deeper in the mind, such as a subjectively experienced sensation) – that is, providing evidence for a latent factor with some external validation (or for the hypothetical construct of an intervening process by converging operations).

Furthermore, the CONceptual and PERceptual processes are by definition conscious, in that they require the verbalised conceptualisation of 'sweet' and/or 'sour.' However, the stimulation-driven processing of the decision to choose does not require activation of the concepts and so could be out of awareness, i.e. truly SUBceptual.

End of Talk 2

References to work mentioned in the Talks

(in order of date of publication)

Booth, D.A., Thompson, A.L. & Shahedian, B. (1983). A robust, brief measure of an individual's most preferred level of salt in an ordinary foodstuff. *Appetite* 4, 301-312.

Booth, D.A., Conner, M.T. & Marie, S. (1987). Sweetness and food selection: measurement of sweeteners' effects on acceptance. In J. Dobbing (Ed.), *Sweetness*, pp. 143-160. London: Springer-Verlag.

Booth, D.A. (1988). Estimating JNDs from ratings. [Abstract: 10th Annual Meeting of the Association for Chemoreception Sciences (U.S.)] *Chemical Senses* 13 (4), 675-676

Conner, M.T., Haddon, A.V., Pickering, E.S., & Booth, D.A. (1988). Sweet tooth demonstrated: individual differences in preference for both sweet foods and foods highly sweetened. *Journal of Applied Psychology* 73, 275-280.

Conner, M.T., Booth, D.A., Clifton, V.J., & Griffiths, R.P. (1988). Individualized optimization of the salt content of white bread for acceptability. *Journal of Food Science* 53, 549-554.

Booth, D.A., Conner, M.T., & Gibson, E.L. (1989). Measurement of food perception, food preference, and nutrient selection. [In C. Murphy, W.S. Cain & D.M. Hegsted (Eds.), Nutrition and the chemical senses in aging: recent advances and current research needs.] *Annals of the New York Academy of Sciences* 561, 226-242.

Booth, D.A., & Conner, M.T. (1991). Characterisation and measurement of influences on food acceptability by analysis of choice differences: theory and practice. *Food Quality & Preference* 2, 75-85. [Ignore an error about 'city-block' scaling]

Kendal-Reed, M., & Booth, D.A. (1992). Human odor perception by multidimensional discrimination from remembered patterns. [AChemS meeting, Abstract 142] *Chemical Senses* 17 (5), 649. [Work later presented at Wartburg Conference, 1994]

Kendal-Reed, M., & Booth, D.A. (1992). Olfactory perception as receptor pattern recognition. [ECRO meeting, Abstract 69] *Chemical Senses* 17 (6), 848-849.

Booth, D.A., & Freeman, R.P.J. (1993). Discriminative feature integration by individuals. *Acta Psychologica* 84, 1-16.

Richardson, N.J., & Booth, D.A. (1993). Multiple physical patterns in judgments of the creamy texture of milks and creams. *Acta Psychologica* 84, 93-101.

Freeman, R.P.J., Richardson, N.J., Kendal-Reed, M.S., & Booth, D.A. (1993). Bases of a cognitive technology for food quality. *British Food Journal* 95 (9), 37-44.

Recently published/submitted reports from Richard Freeman's PhD Thesis

One- and two-dimensional modelling of mixtures of sugars and acids, included in:-

Booth, D.A., Freeman, R.P.J., Konle, M., Wainwright, C.J., & Sharpe, O. (under review). Multi-psychophysical object recognition. Does perception of glutamate require the gustatory glutamate receptor?

Interactions between a sensory feature and a conceptual feature

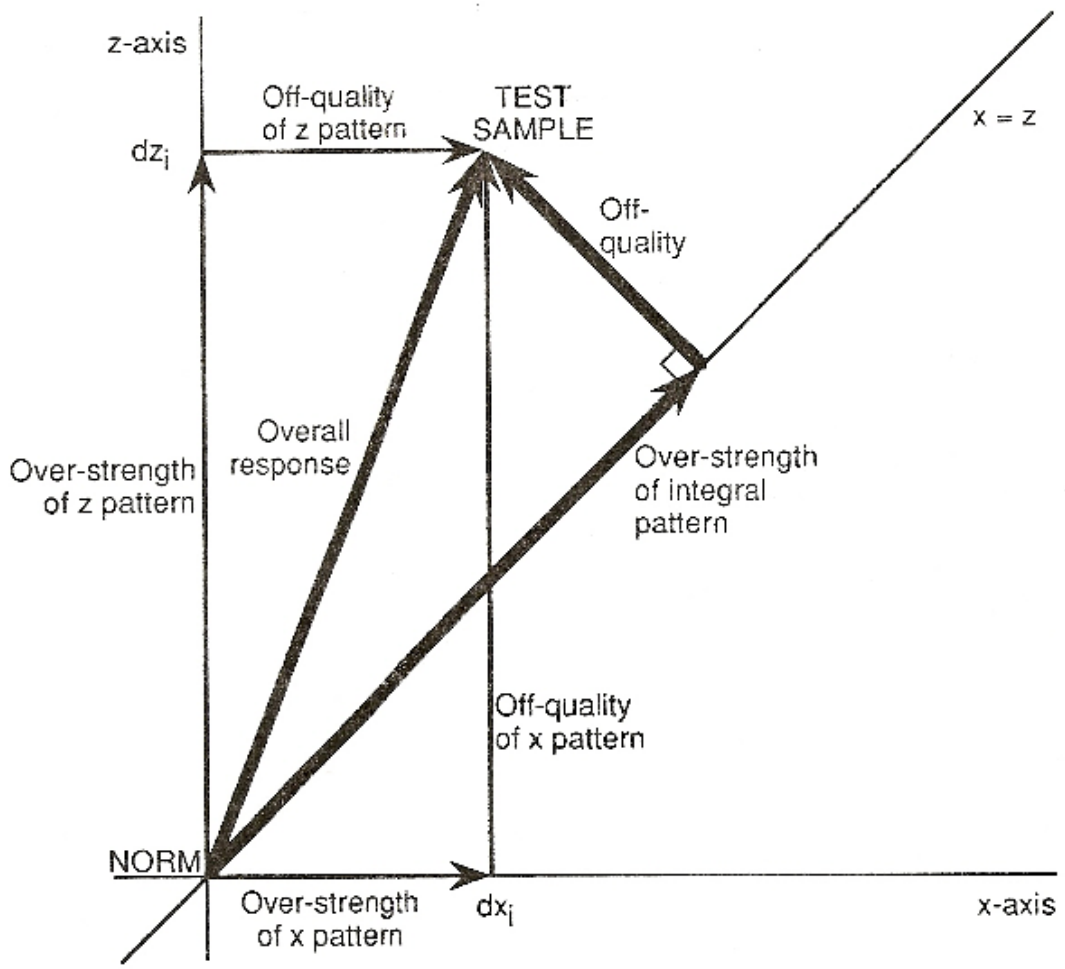
Freeman, R.P.J., & Booth, D.A. (2010). Users of 'diet' drinks who think that sweetness is calories. *Appetite* 55, in press.

Freeman, R.P.J., & Booth, D.A. (under revision). Spreading fat users cognitively segmented by discriminations from personal norm. Conceptualised sensing and sensed labelling.

Postscript *on 'balance' of tastants, odorants etc.* *(cp. MSG 4-taste, strawberry 4-aroma)*

The theory of multiple normed discriminations (Booth & Freeman, 1993) gives a quantitative account of the strength of a variant of familiar mixture of tastants (for example, or of odorants or textural factors etc.) as distinct from its quality or 'balance.'

The algebraic account given in Booth and Freeman (1993) is represetnted graphically below (which is a Figure in that paper).



Binary mixtures with components at higher levels than normal (sensed in the natural material or usual product) will plot as points in this stimulus graph, scaled in HDDs from Norm for responses by an individual in a session.

When the ratio of concentrations of two tastants (or odorants) is identical to that in the familiar version ('template' in object-recognition theory), then the samples fall on the 45^o diagonal of strength of the learnt integration of the material stimulation patterns ('affordances'). At other ratios (like that of the Test Sample in the diagram), quality is not perfect (e.g., over-sweet or over-sour / under-sweet), while the judged strength is that of the nearest Normal ratio.