Authors' MS. Published as *Appetite* 46, 130-136 (2006)

Do you like the sight or the feel of milk in coffee?

Ecology and effortful attention in differential acuity and preference for sensed effects of milk substitute in vended coffee

Nicola J. Richardson-Harman and David A. Booth

School of Psychology, University of Birmingham,

Edgbaston, Birmingham B15 2TT, U.K.

Running head: Colouring *vs*. lubrication

Corresponding author:

Email: D.A.Booth@Bham.ac.UK (David Booth)

Abstract

A rapid method of discrimination scaling was used to measure individuals' acuity for levels of a complex stimulus perceived through several sensory modalities at once in a familiar context. The stimulus was a replacement for fresh milk used in vended coffee. The two experiments reported here compared the performance of ratings of the coffee's milkiness and creaminess when assessors were limited to the use of visual and/or olfactory cues. Better discrimination by milkiness ratings was observed during normal drinking and in a visual-only condition than when only oronasal or oral cues were available. Ratings relative to each assessor's ideal level of milkiness or creaminess showed diversity between assessor-preferred visual and oral characteristics of the milk substitute. However, instructing the assessor to attend to a particular aspect of the sample did not prevent the use of a better discriminated characteristic if available to the senses. These results showed that the acceptability of a beverage or food depends more on the perceptible material than on efforts to direct attention to particular aspects.

Key words. Milkiness. Creaminess. White coffee appearance. Creamy mouthfeel. Intersensory balance. Directed attention.

Introduction

The experimental psychology of perception and attention is highly relevant to the sensory evaluation of food. Yet psychologists have neglected the familiar ecology of eating situations and food research has had little regard for scientific knowledge about the recognition of objects and attention to their features.

It has been found that the global characteristics of a stimulus are more rapidly processed than its local, discrete aspects (Kimchi & Merhav, 1991). Yet it is easier to relate a stimulus to a standard along a single dimension than it is to judge the overall similarity between two stimuli (Shepard, 1964). Also, even when complex stimuli are perceived as an average of the discrete parts (Anderson, 1970), the contribution by each of the parts to the overall percept can vary (Oden & Anderson, 1971).

In food research, the physical bases for sensed characteristics of dairy products have been studied extensively but so far there has been little advance beyond the obvious facts that the more fat that there is in a cream, the thicker it is, and the more milk there is in a dark beverage such as coffee or tea, the paler the drink looks.

The present pair of experiments comes from the start of a project that endeavoured to extend the use of cognitive psychology in sensory research on foods. The project's aim was to apply a rapid method of measuring discriminative performance to the sense of touch in the mouth, following its development for other sensed features of eating situations, such as taste, aroma and colour, as well as for attributed features (e.g. Booth, Thompson & Shahedian, 1983; Conner *et al*., 1986, 1987, 1988a,b; Booth & Freeman, 1993; Freeman *et al*., 1993). This initial study compared the acuity between levels of a complex stimulus perceived through several sensory modalities at once with differential acuities through the modalities separately. The stimulus was various concentrations of a replacement for fresh milk that was used in coffee vended by machine. The sensory

modalities tested separately and in combination were the visual appearance, smell and oral stimulation (touch and taste) of the vended white coffee.

Differential thresholds or acuities have traditionally been determined by laborious 'indirect' procedures such as the Method of Comparisons. Suprathreshold sensitivities as measured by exponents of power functions of numerical estimates of sensed magnitudes are unstable over time and among criteria of judgement (Teghtsoonian & Teghtsoonian, 1983). However, if each stimulus is placed at a position on a line specified by just two anchor points familiar to the assessor (McBride & Booth, 1986) and known biases on quantitative judgement (Poulton, 1988) are minimised by adequate selection of test stimuli, then a small number of ratings from a single assessor gives a log-linear psychophysical function (Booth *et al*., 1983). Least-squares regression through three or more such data provides an estimate of Weber's fraction of the lower of two levels of a stimulus by which the upper level is “just noticeably” different (the JND) over the range of stimulus levels tested (Booth, 1988; Booth *et al*., 2003; Conner *et al*., 1988a). In fact, this estimate is an objective measure of discriminative performance, the difference in levels that is distinguishable with 50% reliability (75% of the occasions), regardless of whether or not a difference was consciously noticed. Therefore “JND” has been replaced by the term half-discriminated disparity (HDD), expressed here as the half-discriminated fraction (HDF = HDD – 1) corresponding to Weber’s Fraction (JND – 1).

Linear regression through the raw data in such a function also provides two less objective parameters of suprathreshold sensitivity, namely the slope of the function (cp. the exponent from log-log plots) and the variance accounted for by the regression equation (Weiffenbach, 1989). In addition, the regression provides estimates of the remembered stimulus levels that correspond to the assessor's use of the anchor points. Hence, when a familiar object or material containing a particular level of the stimulus is used from memory as an internal standard for comparison with test stimuli, this physical

norm can be estimated from the equation – for example, the individual assessor's most preferred level of a sensed constituent of a food.

In the two experiments reported here, levels of milk substitute in a coffee drink were rated relative to the level regularly experienced by each assessor in purchases from a vending machine, as well as relative to the ideal level for that individual.

Use of the rating anchor referring to the familiar drink was supported by a physical standard, namely a cup of vended white coffee which could be sampled at any time during the session. The end anchor was the same for relative-to-standard and relative-to-ideal ratings, to allow comparison between the two interpolated levels of the replacement for milk.

The amount of milk or cream (or their substitute) in a drink of coffee affects both its visual appearance (i.e. the colour) and also its feel, taste and (retronasal) aroma when taken into the mouth. The experiments reported here compared individuals' ratings for discriminative acuity by eye alone with those when blindfolded, and tested the role of olfaction in oronasal acuity by the use of noseclips.

The acuities that were observed provided the basis for testing if greater attention to the visual or oral cues could be achieved by verbal instruction alone. Different descriptors of the effect of the milk replacement ("milky" and "creamy") were also compared. Finally, the ratings relative to ideal enabled the assessor-preferred visual and oral characteristics of this particular dairy substitute to be contrasted.

Method

Participants

The assessors in both Experiments 1 and 2 were four female and two male drinkers of unsweetened white coffee who were members of the University Department of Psychology. Their ages ranged between 22 and 38 years.

Five participants took part in both experiments; a 24-year-old woman in the first experiment was not able to participate in the second and so a 32-year-old woman was recruited instead.

Materials

The ingredients for each test sample of coffee drink were 1.5 g of instant coffee (Gold Blend Granulated), varying amounts of milk powder (Sainsbury Coffee Plus) and 120 ml of hot water. The stock weights of whitener were 0.25, 0.5, 0.63, 1.0, 2.0, 4.0, 8.0, 16.0 and 32.0 g per cup (steps in ratio of 2 with an interpolation among the lower levels). The standard sample of coffee approximated to that in the departmental vending machine; it contained 4.0 g of milk substitute, 1.5 g of instant coffee and 120 ml of hot water.

The dry ingredients were prepared not more than 24 hours in advance and stored in vending machine cups with air-tight lids. Each test drink was prepared immediately prior to presentation to the assessor by the addition of water heated to 70-80 °C.

Experimental conditions

There were four assessment conditions of Experiment 1. These were: Normal -- the coffee sample was drunk in the normal manner, allowing the use of both visual and oral cues; Visual only -- the assessor was allowed only to look at the coffee sample; Oronasal-only, where the assessor drank the coffee wearing a blindfold; and Oral-only -- the assessor drank the coffee sample wearing a blindfold and a noseclip.

The assessors rated the samples in Experiment 1 relative to a physically presented standard, namely a coffee drink containing the vended amount of this replacement for milk. During the normal condition, the assessors were directed to attend to either (in counterbalanced sequences) the "look" or the "feel" of the drinks.

In Experiment 2, each assessor rated the coffee samples in three of the above four conditions -- namely Normal, Visual-only and Oral-only -- using both relative-to-standard and relative-to-ideal formats.

Rating formats

Prior to presentation of the first sample of coffee drink, the assessors were instructed in the use of each type of layout for rating samples.

Relative to ideal. Assessors were asked to write a stroke across a 10-cm horizontal line at the position that best reflected their likelihood of choosing the sample. The ends of the line were labelled with the phrases "so far from my ideal that I would never choose this drink" (on the left) and "just right - so I'd always choose this drink" (on the right). The assessors were also asked to state whether there was an excessive or inadequate amount of “whitener” in the sample for their preference, by circling one of the two phrases "too much" or "too little". The preference ratings were scored in millimetres from the end labelled "always choose this drink" and given a negative sign if the level of milk substitute was categorised as "too little".

Relative to standard. Ratings on a 10-cm line were measured in millimetres from the midpoint, labelled either "as creamy as vended" or "as milky as vended", with an anchor at the left-hand end of "not at all creamy" or "not at all milky" respectively. In the normal condition the instruction to attend to either the appearance or the mouthfeel of the drinks was made by extending the midpoint anchor to read, respectively, either "feels as creamy as vended" or "looks as creamy as vended" and "feels as milky as vended" or "looks as milky as vended", with the same left-hand end-anchor of “not at all” creamy or

milky. Ratings between the anchors "as vended" and "not at all" were scored negative. There was no label on the right-hand end of any of these layouts, because the introduction of a third category cannot be assumed to retain linearity (i.e. equal psychological distances between anchor phrases).

As each new sample was presented, the assessor was reminded that a sample of the vended drink was available for viewing and/or tasting. If the assessor asked for that sample, the experimental sample was removed and replaced by a freshly prepared cup of the standard drink, thus avoiding simultaneous visual comparison and yet providing a fresh-looking and fresh-tasting hot sample.

Procedure

There were four sessions of assessment in Experiment 1 and three in Experiment 2. The sessions took place at a convenient time of morning or afternoon when the assessor might normally have a coffee break. There was an interval of 1-4 days between sessions. For the five assessors who took part in both experiments, there was an interval of 2-4 weeks between the normal sessions (the only assessments on which between-experiment comparisons were considered to be appropriate).

The assessors were requested to refrain from eating and drinking for two hours before the start of the session. The samples were presented one at a time without codes. Water was available for rinsing between samples. Except for the first sample of each session, the milk substitute levels were chosen in the light of previous data from the individual assessor, in accord with principles described elsewhere for minimising known biases within each session (Booth *et al*., 1983). No indication was given of the number of samples to be tested during the session, nor was the total amount of coffee to be consumed by the assessor pre-specified by the experimenter. Nevertheless, to keep assessment within the familiar context of drinking this vended coffee, the number of samples presented was restricted by a maximum of the volume of coffee consumed by

the assessor during the session of not more than about 160 ml (the volume of liquid in the vended cup of coffee). As a result, assessors tested 5-8 samples per session.

Analysis of data

Ratios of the concentrations of milk substitute presented to an individual under one condition in a session were linearly regressed by the least-squares method onto the ratings from each of the two formats in turn. The performance of a type of rating by an assessor at discriminating between levels of milk substitute under a given condition of exposure to the senses was estimated from the slope and error of the regression as the classic ratio of concentrations, (subjectively termed) the 'just noticeable' difference (JND). This degree of acuity is conveniently expressed in the form of Weber's fraction (JND – 1): this is the fraction above the lower of two concentrations that is discriminated 50% of the time as the higher level of stimulation, therefore known in this paper by the objective term of the half-discriminated disparity (HDD), with Weber's fraction (HDD – 1) being the half-discriminated fraction (HDF). This measure of discriminative acuity applies to any graded (and untransformed) response to the stimulus, including ratings from anchor phrases that imply preference, not simply intensity.

The estimation of the HDD (JND) derives from its definition as that ratio of stimulus levels for which the stronger stimulus is rated in 75% of instances as higher than any weaker stimulus that it may be by chance compared with (Torgerson, 1958). This 75% criterion is met when the response distributions to the two stimuli (stronger and weaker) overlap by 50% of each distribution; this overlap corresponds to a z score of 0.675 from each mean. The resulting formula for the Weber fraction is

$$\mathrm{HDF} = \mathrm{antilog}\,(2 \times 0.675 \times \mathrm{SD}/m) - 1,$$

where SD is the square root of the mean response variance (mean squared error) and m is the slope of the regression line (Conner *et al*., 1988a,b). It should be emphasised that this is a calculation of actual performance in a particular set of assessments – what was half

discriminat*ed*; this concept is quite different from the usual notion of an abstract characteristic of the human senses, whether subjectively notice*able* or objectively discrimin*able* (or indeed the average exponent of power functions for a modality).

The HDFs were used as the dependent variable in further analysis. Interpolation of the individual's midpoint of the rating format from the regression line gave either the ideal or the estimated standard level of the milk substitute, depending on the anchor used in the format (Figure 1).

Figure 1 about here

Results

Experiment 1

The individuals' differential sensitivities (half-discriminable disparities: HDFs) to the milk substitute varied among the four conditions tested (normal, oronasal-only, oral-only and visual-only: Figure 2), $F(3,59) = 3.34$, $p < 0.05$. The HDFs averaged across ratings of milkiness and creaminess for the oronasal-only (1.55) and oral-only (1.89) conditions were higher than those for the normal (0.27) and visual-only conditions (0.28). The two visual conditions together (normal and visual-only) were compared statistically with the non-visual conditions (oronasal-only and oral-only). Ratings of milkiness were reliably more sensitive (lower mean HDF) in the visual conditions than in the non-visual conditions (Figure 2, upper panel), $F(1,23) = 8.30$, $p < 0.01$, although this difference did not reach significance for creaminess (Figure 2, lower panel), $F(1,23) = 3.38$, $p < 0.1$.

Figure 2 about here

For the oronasal-only and oral-only conditions, the standard deviations of the HDFs across the six assessors were higher for “creamy” than for “milky” (Table 1).

Table 1 about here

The instructions to “look” at each sample of coffee or to “feel" it while drinking did not have a statistically significant effect on discrimination between whitener levels by ratings of milkiness, $F(1,10) = 2.95$, $P < 0.2$, or of creaminess, $F(1,10) = 0.43$ (Figure 3). Main and interaction effects of assessor (1-6), descriptor ("creamy", "milky") or instruction ("look", "feel") on HDF in the normal drinking condition were not significant in a four-way analysis of variance. Only one assessor (number 6) might have been influenced consistently by the instructions (Figure 3). In three assessors, the HDF value moved between “look” and “feel” instructions in the same direction for “creamy” and “milky” ratings; however, this differential acuity worsened in two of them (Assessor 6 and slightly in Assessor 2) and improved in one (Assessor 5). However, the effect on discriminative performance of the instruction to “feel” rather than to “look” might prove in further work to be better for ratings of creaminess than for ratings of milkiness: there was a decrease in HDF in five out of the six assessors tested (a frequency giving $p < 0.11$ in a one-tailed sign test).

Figure 3 about here

The mean of the levels of milk substitute perceived to be in the vended standard by interpolation from individuals’ regressions of levels onto creaminess ratings was 3.44 g and that for milkiness was 3.49 g. Although these values underestimate the vended level

of 4.0 g of milk substitute per cup, the degree of underestimation was consistent across the two descriptors.

It should be noted from what follows, however, that the assignment of positions of the coffee drinks towards “not at all” was exaggerated for how “creamy” a coffee seemed relative to how “milky” it was – a response bias in the opposite direction to the tendency for the discriminative performance (HDF). Out of the 30 possible pair-wise comparisons (i.e., 6 subjects in 4 conditions, the normal condition being represented twice for both instructions), 26 of the slopes of the creaminess functions were steeper than the slopes for milkiness against ratios of concentration of milk substitute. Consistently with that frequency measure, the mean slope value for creaminess (76.2) was reliably greater than that for milkiness (64.6), $t(28) = 2.43$, $P < 0.05$. That is, deviation of the level of milk substitute from that in the marketed drink had a greater effect on creaminess scores than on milkiness scores, despite (or because of?) the latter having if anything better differential acuity.

Experiment 2

The six assessors' ideal levels of the replacement for fresh milk varied significantly across conditions, $F(2,15) = 4.97$, $P < 0.04$, with the means of conditions being visual-only 3.22, oronasal-only 4.02 and normal 4.85 g/cup. However, the interpolated estimates of vended level perceived by assessors did not vary significantly across sensing conditions, $F(2,15) = 0.34$, with means of 4.10, 4.05 and 4.30 g/cup (actual level 4.0).

The perceived vended levels of whitener under the normal condition were correlated between the two experiments for the five assessors who took part in both, giving values of r for the different types of rating that ranged from 0.69 to 0.95 (all $p< 0.05$). Thus, a familiar standard provided a stable anchor over the interval of 2-4 weeks between tests, indicating its adequacy for measurements of an individual assessor’s sensitivity to differences among samples.

However, sensitivity did not differ significantly between instructions to look or to feel in assessments relative to a physical standard under normal conditions of drinking, for ratings of either milkiness, $F(1,10) = 1.86$, $P < 0.25$, or creaminess, $F(1,10) = 0.47$.

Discussion

It has been proposed that attention is more likely to be attracted or directed to features of an object if they can be located within a "master map" which is based upon previous exposure (Treisman, 1991). One possible explanation of the finer acuity for visual cues to concentration of milk substitute found in this study is that people use immediate visual information informed by past experiences of later oral/textural effects to decide how much milk they want in their coffee. Hence, when both cues are present, the more practised discrimination is used. A qualification on this interpretation should be noted, however. It has recently been shown that the more acute of the discriminations of two modalities does not “dominate” absolutely; rather, the overall performance is a compromise between the two discriminations (Ernst & Banks, 2002). However, the present data are insufficient to provide a test of this interpretation.

It would be unwise to take the present results as evidence for the notion the sense of sight is inherently more acute than other senses such as touch and smell, let alone vision being the “dominant” sense in human beings. Even for as simple an act as drinking a cup of white coffee, the results of these experiments point to the need for properly detailed consideration of the ecological affordances for perception (Gibson, 1979). These physical issues are implicit in the terminological distinction that a consumer might draw between a “whitener” and a “creamer.”

Adding milk or an artificial whitener to fresh or reconstituted infusate of coffee causes an increase in the scattering of light near the surface of the liquid, achieved by particles that reflect all visible wavelengths. As the concentration of milk or its

replacement is increased, the drink passes from transparent through translucent to opaque, while the brown colour of the coffee is increasingly masked, until the drink becomes almost as pale as milk.

Adding cream, or a powder that substitutes for cream, may have a less dramatic effect on colour but is expected to produce a definitely creamy texture in the mouth. Indeed, use of a high concentration of cream or cream substitute may induce its fat droplets to coalescence into visible pools of oil on the surface of the drink, leaving the fluid a strong brown colour still. Even below such levels, the creaminess induced by an artificial 'creamer' can be so intense as to be excessive to some tastes.

It has been claimed that viscosity is the only physical characteristic at the basis of creamy texture (e.g., Mela *et al*., 1994). Yet neither a milk substitute nor a cream substitute need be used in high enough concentration to cause a substantial increase in the viscosity of the drink. A replacement for cream can be made of microscopic globules of fat set in a matrix of maltodextrin, which dissolves in the hot coffee to leave the globules in suspension. Whether the fat is solid or liquid, these spheres will be rigid and so might act like a micrometre-scale ball-race to lubricate movement between the tongue and the palate, in a different way from the mucins in saliva, or indeed from plain water or oil (Richardson, Stanley & Booth, 1993).

A replacement for milk, on the other hand, may not rely on fat droplets so much or at all to reflect light but it may act more as a clouding agent, with weaker affordances to the sense of touch. Despite any such contrast with a cream substitute, the milk substitute used in these experiments had sufficient effect on mouthfeel for it to be possible for attention to be called to oral stimulation. Nevertheless, this brand of milk substitute seems to have been designed more as a paint than as a lubricant!

However, perception is not entirely driven by ecology. As well as attention being effortlessly attracted by a feature of an object, perceptual processing can in some cases

be deliberately shifted to some extent onto one feature rather than others. Some efforts to direct an individual's attention to a particular feature have not succeeded, for example for particular fingers with vibrotactile stimulation (Evans & Craig, 1991) and for tastants in mixtures (Moskowitz, 1972). Closer to the present experiments, comparisons of vision with other sensory modalities have long found greater acuity for visual cues (e.g. Brown, 1960; McKennel, 1958). Indeed, Pangborn (1964) found that textural evaluations of drinks were strongly influenced by their appearance, apparently without the assessors realising it.

Nevertheless, in the present work the request to the assessor to direct attention to mouthfeel showed signs of improving acuity to differences in concentration of the milk substitute when rating the coffees on "creamy," to a greater extent than when rating on "milky." Such a difference between descriptors might arise from a difference between real milk and cream in the role of cues from the mouth in recognition of the material. Touch (and aroma) may be more salient features of creams than of milks. If an assessor's sensory concept of milk did not include mouthfeel, rating of milkiness might be incompatible with attending to feel by the mouth. Even if the difference between concepts of milk and cream is not as extreme as that, it could still be more difficult to attend to the feel of the milk substitute while comparing it to milk than when comparing it to cream.

Perhaps the most important general implication of the present results comes from the finding that individuals' sessions differed in which affordances informed perception: on the one hand, there was more variability when personal preference directed attention; on the other hand, there were signs of a systematic shift when the effort was made to switch attention between sensory modalities and verbal comparators. Since some of this selective attention can be affected by experimental conditions, variations in effortful and effortless attention presumably occur also under different conditions of everyday

drinking and eating. Hence we are unlikely to understand the balance between visual and oral cues in milks and creams in use unless we use stronger designs than mere descriptive profiling. The sensory influences on drinking and eating need to be investigated on the basis that individuals may differ in which of the available features control recognition of good quality of beverage or food material (Booth, 2005). Research must also allow for the likelihood that the influential features vary among contexts of consumption. In addition, an individual's performance within a particular context may be affected by externally uncontrolled differences.

The findings from the present quite small amount of data indicate considerable potential for this approach in sensory psychology. Frequently used research designs may be insufficiently constrained. Samples need to be selected to minimise biases that can cause the psychophysical function to depart from linearity (Conner *et al*., 1986). Indeed, if an assessor is taken outside the linear range of distances from ideal, the function may depart so far from the quadratic fitted by generic psychological models of preference (Coombs, 1984) that the statistical software based on this inverted U (e.g. MDPREF) can produce unusable illogicalities such as "anti-ideals." Furthermore, the measurement of influences on eating options can only be valid, let alone precise, if the collection of data is carried out session by session with individuals acting on foods in a context which is recognisably similar to a personally familiar use of that food.

Acknowledgements

The authors thank the former Agricultural and Food Research Council (U.K.) and Unilever Research Ltd. for financial support and Prof. Adam Drewnowski for his helpful comments. Dr Richardson-Harman now works in the USA and may be contacted on email at <njharman@aol.com>

References

Anderson, N. H. (1970). Functional measurement and psychophysical judgment. *Psychological Review* 77, 153-170.

Booth, D.A. (1988). Estimating JNDs from ratings. [AChemS abstract] *Chemical Senses* 13 (4), 675-676.

Booth, D.A. (2005). Perceiving the texture of a food: biomechanical and cognitive mechanisms and their measurement. In E. Dickinson (Ed.), *Food colloids: interactions, microstructure and processing*, pp. 339-355. Cambridge: Royal Society of Chemistry.

Booth, D.A., & Freeman, R.P.J. (1993). Discriminative measurement of feature integration in object recognition. *Acta Psychologica* 84, 1-16.

Booth, D.A., Mobini, S., Earl, T., & Wainwright, C.J. (2003). Consumer-specified instrumental quality of short-dough cookie texture using penetrometry and break force. *Journal of Food Science: Sensory and Nutritive Qualities of Food* 68, 382-387.

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

Brown, I. D. (1960). Visual and tactile judgments of surface roughness. *Ergonomics* 3, 51-56.

Conner, M.T., Haddon, A.V., & Booth, D.A. (1986). Very rapid, precise measurement of effects of constituent variation on product acceptability: consumer sweetness preferences in a lime drink. *Lebensmittel-Wissenschaft und -Technologie* 19, 486-490.

Conner, M.T., Land, D.G., & Booth, D.A. (1987). Effects of stimulus range on judgments of sweetness intensity in a lime drink. *British Journal of Psychology* 78, 357-364.

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

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

Coombs, C.H. (1964). *A theory of data*. New York: Wiley.

Ernst, M.O., & Banks, M.S. (2002). Humans integrate visual and haptic information in a statistically optimal fashion. *Nature* 415, 429-433.

Evans, P. M., & Craig, J. C. (1991). Tactile attention and the perception of moving tactile stimuli. *Perception and Psychophysics* 49, 355-364.

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.

Gibson, J.J. (1979). *The ecological approach to visual perception*. Boston: Houghton Mifflin.

Kimchi, R., & Merhav, I. (1991). Hemispheric processing of global form, local form, and texture. *Acta Psychologica* 76, 133-147.

Mela, D. J., Langley, K. R., & Martin, A. (1994). Sensory assessment of fat content: effect of emulsion and subject characteristics. *Appetite* **22**, 67-81.

McBride, R. L., & Booth, D. A. (1986). Using classical psychophysics to determine ideal flavour intensity. *Journal of Food Technology* 21, 775-780.

McKennel, A. C. (1958). Wool quality assessment. *Occupational Psychology,* 32, 111-119.

Moskowitz, H. R. (1972). Perceptual changes in taste mixtures. *Perception and Psychophysics,* 11, 257-262.

Oden, G. C., & Anderson, N. H. (1971). Differential weighting in integration theory. *Journal of Experimental Psychology* 89, 152-161.

Pangborn, R. M. (1964). Difference-preference evaluation of milk by trained judges. *Journal of Dairy Science* 47, 1414-1416.

Poulton, E. C. (1988). *Bias in quantifying judgements.* New York: Academic Press.

Richardson, N. J., Booth, D. A., & Stanley, N. L. (1993). Effect of homogenization and fat content on oral perception of low and high viscosity model creams. *Journal of Sensory Studies* 8, 133-143.

Shepard, R. N. (1964). Attention and the metric structure of the stimulus space. *Journal of Mathematical Psychology* 1**,** 54-87.

Teghtsoonian, M. & Teghtsoonian, R. (1983). Consistency of individual exponents in cross-modal matching. *Perception and Psychophysics* 33, 203-214.

Torgerson, W. S. (1958). *Theory and methods of scaling*. New York: Wiley.

Treisman, A. (1991). Search, similarity, and integration of features between and within dimensions. *Journal of Experimental Psychology: Human Perception and Performance* 17, 652-676**.**

Weiffenbach, J. M. (1989) Assessment of chemosensory functioning in aging; subjective and objective procedures. *Annals of New York Academy of Sciences 561,* 56-65.

Table 1. Half-discriminable differences for milk substitute in coffee drinks rated by six assessors for milkiness and creaminess under four conditions (Experiment 1).

Instruction	Rating	Normal		Visual only		Oral-only		Oronasal-only	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Look	Milky	0.14	0.03	0.21	0.04				
	Creamy	0.17	0.07	0.27	0.21				
Feel	Milky	0.26	0.17			2.14	2.24	1.46	1.62
	Creamy	0.22	0.17			1.64	3.05	1.64	2.63

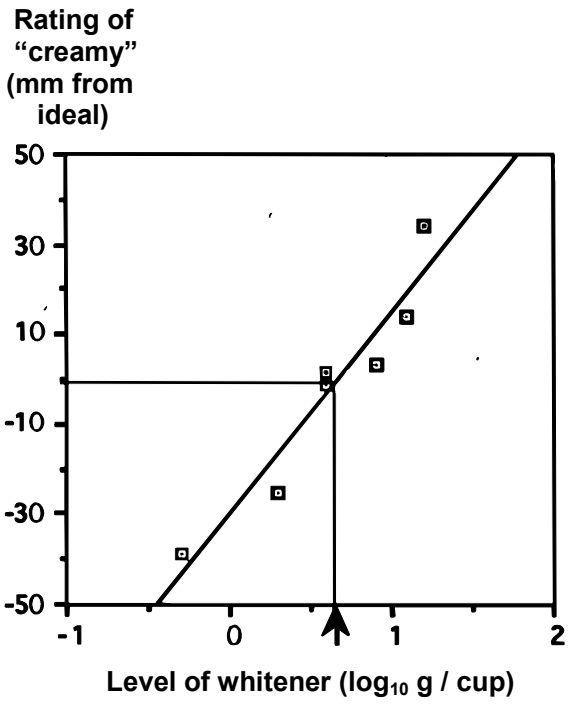
Figure Captions

Figure 1. A typical assessor's ideal-relative intensity ratings of levels of milk substitute in coffee in the visual-only condition (Experiment 2). The regression of whitener levels onto rated distance from ideal allows interpolation of the ideal level of milk substitute, marked with an arrow.

Figure 2. Means (N = 6) of across-panel HDFs (with SD bars) under four experimental conditions for the ratings of how “milky” or “creamy” were coffee drinks containing milk substitute at concentrations that were varied among the test samples (Experiment 1).

Figure 3. Individuals' HDFs for the milk substitute from ratings of creaminess and milkiness under instructions to 'look' (stippled bars) or to 'feel' (cross-hatched bars) in the normal condition of drinking (Experiment 1).

Richardson-Harman & Booth
Figure 1



Richardson-Harman & Booth
Figure 2

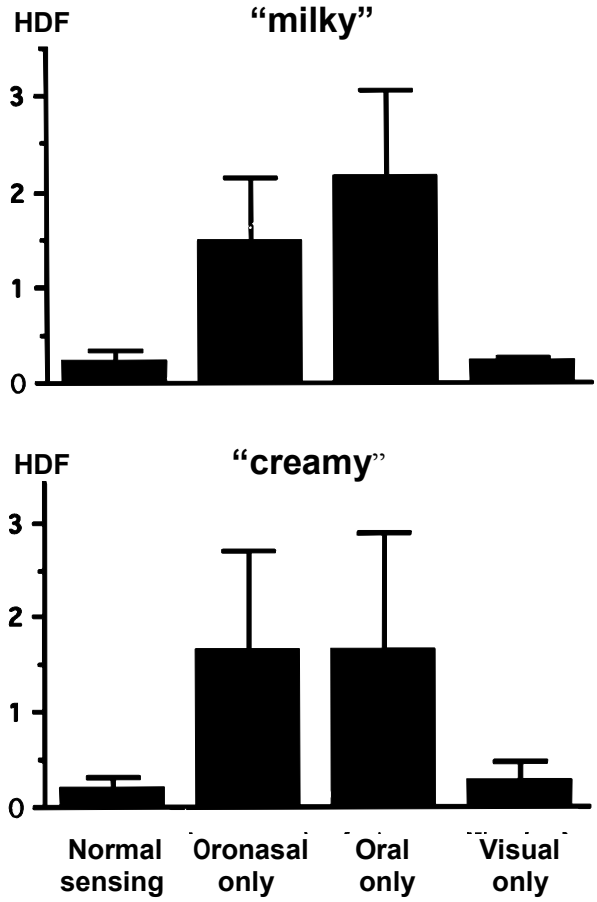
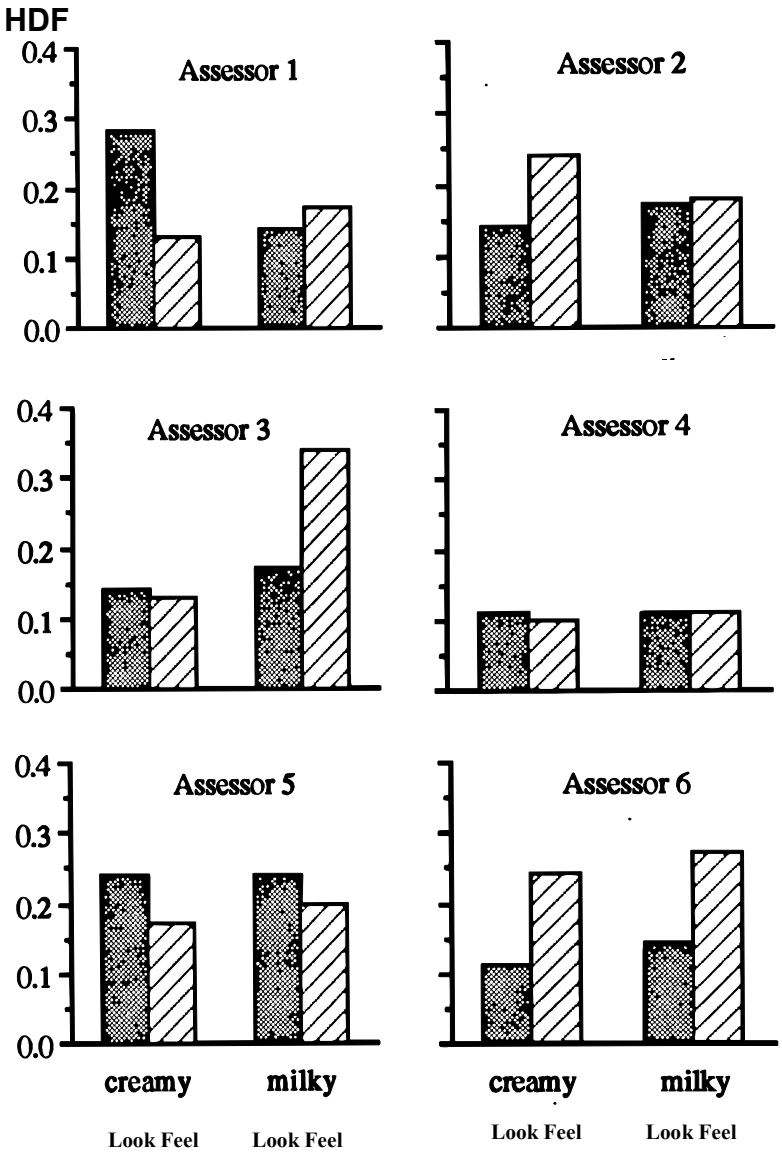


Figure 3


HDF
Assessor 1
Assessor 2
Assessor 3
Assessor 4
Assessor 5
Assessor 6
0.4
0.3
0.2
0.1
0.0
creamy
milky
Look Feel
Look Feel
creamy
milky
Look Feel
Look Feel