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Short Communication to *Appetite*

A strawberry by any other name would smell as sweet, green, fruity and buttery. Multisensory cognition of a food aroma

D.A. Booth,* M.S. Kendal-Reed, R.P.J. Freeman

School of Psychology, College of Life and Environmental Sciences, University of Birmingham, Edgbaston, Birmingham, West Midlands, B15 2TT, UK

*Corresponding author. Email address: D.A.Booth@Bham.ac.UK (David Booth)

Footnote 1 (Acknowledgements)

This Short Communication presents all the data now available from an oral presentation in 1994 to the 4th Wartburg Castle Aroma Symposium in Eisenach. These findings from two assessors, together with an account of the theory (Booth & Freeman, 1993) and its historical background were included in the Proceedings distributed by the organisers (Booth, Freeman & Martin-Reed, 1995).

The experiments were designed and executed by Dr. Martin Kendal-Reed as part of a research project funded by the cognitive science initiative of the Biology branch of the UK Science and Engineering Research Council. The data were analysed by a tool programmed in QuickBasic by Richard Freeman on a CASE Studentship funded by the UK Ministry of Agriculture, Food and Fisheries. Histograms of the cognitive data from Case B are included as Figure 3 in the authors' manuscript on http://www.psychology-people.bham.ac.uk/people/david.booth

We thank Dr. S. Jellinek of Dragoco GmbH for a stock solution of each of the four odorants, plus solvent for the dilutions.

Dr. Freeman is now at the Doctoral School of the Institute of Education in the University of London, U.K.

ABSTRACT

This brief report presents illustrative findings from the first implementation for recognition of an aroma of individualised analysis of cognition as normed discriminations. Two assessors compared mixtures of four odorants with a fresh strawberry in overall aroma, its intensity and balance, and in the smell of each odorant conceptualised in their own words. By the second session, each assessor's judgments of overall likeness of a mixture to strawberry focused on one of the six mental processes tested. One assessor acquired a configural conceptualisation of all the odorants as smelling the same as strawberry. The other asssessor learnt to rate strawberriness by conceptualising the four odorants separately in judgments of both intensity and balance. Even this modest amount of data provides insights into mental mechanisms by which an individual perceives the complex profile of odorants released by a familiar material.

Keywords

Multisensory integration

Strawberry volatiles

Odour mixtures

Personal cognition

Normed discrimination scaling

Configural learning

Introduction

What's in a name? A rose by any other name would smell as sweet.

- William Shakespeare (*Romeo and Juliet*)

The strawberry's olfactory norm

This paper reports the first implementation for olfaction of an approach to multisensory, multiconceptual cognition based on discrimination from a learnt configural norm (Booth & Freeman, 1993). The norm was the aroma of a ripe strawberry. The samples discriminated from those volatiles were mixtures of four odorants, each having its own assessor-named aroma note. The theory's applicability to such conceptual features of an object as well as to its sensed material features had been demonstrated for the sweet taste of an orange-flavoured drink and the calories symbolised by its labelling (Freeman & Booth, 2010; Freeman *et al*., 1993). The first multisensory example of the approach was the learnt balance between sugars and acids in the same drink (Booth & Freeman, 1993; Freeman, 1966).

Each of these multifeatured examples of ingestive appetite showed that two sources of information could have aspects that are recognised as the same and other aspects that are distinct from each other. Sucrose and fructose operated as the same feature in overall flavour of the orange drink (Booth & Freeman, 1993) as shown for sugars in water using classic discrimination methodology (Breslin, Beauchamp & Pugh, 1996). Citric and malic acids were also indiscriminable by this criterion (cp. Breslin & Beauchamp, 1995). Yet, as expected, the sugars and the acids made readily distinguished contributions to the drink's flavour in binary or quaternary mixtures (Freeman, 1996). A more complex gustatory example was the glutamate in tomato juice: this was shown to share affordances (Gibson, 1979) by sucrose, citric acid and caffeine. Hence an appropriate balance of the four classic types of tastant was indiscriminable from monosodium glutamate in the learnt taste of a salted tomato juice beverage (Booth, Konle & Sharpe, 2008; Freeman *et al*., 1993).

These studies of mixtures of tastants in drinks all involved symbolic features as well as material features. Correct use in English of the word "sweet" is learned from the commonality in taste between ripe fruit of different species, honey and sugar-containing foods and drinks. The concepts of sourness, saltiness and bitterness are learnt in the same way (Booth, 2008). The concept of a distinct taste of the glutamate and sodium salts in many plant and animal foods comes also from that commonality sensed in the meat and vegetables of the main course of a hot meal and so is known by the name of that course – savoury. Yet learning a name is not just learning the word. The object so named in the culture also has to be learnt and then the sensory pattern associated with the linguistic pattern (Wittgenstein, 1953). Indeed, errors in remembering which word goes with which olfactory input can occur largely at the perceptual stage of processing (Cain & Potts, 1996). Hence the mixtures of volatile compounds from the flowers, fruit or leaves of plants also have to be learnt as a whole if they are to be recognised. The implications for the perception of experimental mixtures have not been well recognised. Assessors are presented with arbitrary mixtures of two or more compounds to smell or taste, with no chance to learn a configural norm for a particular set of compounds; hence (re)cognition is not possible (Booth, 1995). The compounds can only mask each other (Cain *et al*., 1995; Marshall *et al*., 2006). The masking gets worse if configural learning is prevented by training to attend to one of the compounds (Kurtz, Lawless & Acree, 2009; Prescott & Murphy, 2009). In contrast, discrimination of each component by the overall concept of the familiar material is better than it is by each descriptive concept in the case of a savoury-tasting mixture of tastants (Booth, Konle & Sharpe, 2008).

Configuration of odour is now being widely invoked (Jinks & Laing, 2001; Zou & Buck, 2004) but without considering its cognitive mechanisms (e.g., Pearce, 1994). The Gestalt of a particular mixture of two or more odorants can be learnt without loss of ability to separate their odours. The question is how the learnt processing treats the components. Do the originally different odours become sensed or conceptualised as the same? Do they remain totally distinct but fit the new description acquired for the mixture's norm? The cognitive modelling used in this paper calculates answers to such questions.

Four recognisable aroma notes dominate the smell of a strawberry. Since we learn to label smells by their sources, each note is named after another object or sort of material. The sweet aroma probably arises from familiarity with caramelised sugary foods. Green (or leafy) refers to the greenery on trees and bushes. Fruity is presumably a smell reminiscent of many species of fruit when ripe. Butteriness is learnt from the dairy product or from aroma volatiles added to vegetable-based spreads to give a buttery flavour.

The remarkable fact exploited by the experiments illustrated in this paper is that compounds having odours similar to each of these four sorts of material, when mixed in the appropriate proportions, have an aroma hard to distinguish from that of strawberries. The multi-receptor profile of each compound (Polak, 1973; Malnic *et al*., 1999) may compensate to some degree for deficiences in the profiles of one or more of the other compounds because each is similar, but not identical, to a major volatile in the headspace from strawberries (Ulrich *et al*., 1997). The fruity compound in the strawberry mixture is an ester but with a sharper note than the esters predominant in strawberries. Similarly, the leafy green smelling compound was a derivative of hexane (6-C) but not that dominant in strawberry itself. Maltol arises from roasting malts and smells of caramel. Diacetyl occurs in butter in low enough levels to be characteristic of dairy fat rather than its origin.

Personal cognition as discriminations from learnt norm

Ratings of strawberriness and of the notes of each odorant in the test mixture need to be anchored on the aroma of a strawberry. Then the perceived distance from the configural norm of the level of each odorant in a sample mixture can be put on a scale in units of discrimination. Since all distances are in the same unit, they can be combined algebraically without any assumptions about how concentrations of different compounds relate to each other or to the rated intensities under concepts.

There are two possibilities. If two normed discrimination functions are the same process, then a sample's discrimination distances above or below norm should add together, operating in the same dimension. If two odorants, notes or descriptions are perceived as qualitatively different, then their normed discriminations should be orthogonal, combining as the square root of the sum of the squares of the distances.

As there were four odorants with a concept each, four-dimensional (4-d) models were tested. These calculations work if there are only three or two effective discriminations, or indeed just one. Similarly, the unidimensional (1-d) models had four components but the additive formula works even if fewer than four inputs were discriminated. Poor discrimination merely places all the samples close to the norm.

Does the testing of variants involve learning?

Assessors were run for at least two sessions because learning was likely the first time that judgments are made among variants of a complex object. In the earlier work on unisensory variations of foods and drinks, the effects of successive sessions were tested but no clear evidence of learning was seen in those relatively simple tasks (Conner & Booth, 1992; Conner *et al*., 1988). Therefore we looked for evidence of development over sessions in the precision and consistency of the cognitive processing of each assessor.

Method

Participants

Each assessor was familiar with strawberries and liked eating them as the fresh fruit. Both reported that they were in good health, had no food or chemical sensitivity and did not smoke. Neither assessor had nasal symptoms on the day of testing. Normal olfactory perception was confirmed by comprehensible naming of each odorant's aroma.

Materials

Each of four analytical-quality compounds was dissolved in an odourless solvent at a concentration in ratios to the other three compounds' concentrations that gave a roughly balanced strawberry aroma on evaporation to saturate a shared airspace. One compound by itself (maltol) smells sugary and was conceptualised by the experimenters as "sweet." One of the six-carbon compounds found in strawberries smells like leaves such as those on the hull of the berry; its note was called "green." An ester that complemented the mixture of maltol and the 6-C compound better than strawberry aldehyde had a "fruity" aroma. Much lower concentrations of diacetyl were used to give a "buttery" note to the test mixtures.

A known concentration of each odorant was put on its own smell strip and allowed to saturate the airspace in a 30-ml glass tube in accord with its own partition coefficient between the solvent and air. In the main assessments, the four strips or an uncut and unhulled strawberry were put in the tube at least on hour before use. To rate the mixture of odorants, the assessor was instructed to take a single normal sniff as soon as a closure was pulled back from the top of the tube immediately under one nostril. This procedure allows some dilution of the saturated vapour in the tube by room air drawn into the nostril by the sniff. However that does not affect the air concentration ratios among the four odorants. Also the dilution is liable to vary randomly among sniffs. Hence the cognitive modelling of assessed strength of strawberry aroma was subject to more noise in the data than the calculations for balance but remained theoretically valid for orthonasal olfaction.

Assessments

Each assessor's training in the sniffing procedure was used also to elicit a term to conceptualise the smell of each odorant alone. These preliminary tests were therefore on each of the odorants in turn and the strawberry aroma itself.

Each session of the main assessments began with a sniff of strawberry vapour that was not rated and then seven ratings as rapidly as possible after the sniff of a quaternary mixture. First, instantly on sniffing, the assessor decided the rating of overall closeness of the mixture's smell to real strawberries and marked a position between "exactly like strawberries" and "not at all like strawberries." The assessor then started analysis of the aroma by rating closeness in strength of that mixture to the strength of aroma of strawberry to the sniff and closeness in overall balance to genuine strawberry. Finally, from memory, the assessor rated the closeness of each of the notes from the sniffed mixture to the level in strawberries, using the terms chosen in the preliminary test.

Normed discrimination modelling

The unit of discrimination was the disparity between two levels of an odorant, a rated concept or the odorant/note function at which the estimated distributions of response values overlap by half – that is, the upper quartile of the lower level coincides with the lower quartile of the higher level. This calculation is traditionally known as the JND or difference limen (Torgerson, 1956) with levels of material stimuli in ratios of the physical measurement. Each function was estimated by least-squares linear regression from the stimulus values to the response values (Conner *et al*., 1988b). The norm value of the stimulus was the point on the regression line for the anchor "exactly like strawberry."

Discrimination distance from norm for regression to the rating of strawberriness (overall, strength or quality) were calculated for each sample for the odorant (S), the rating of a note (R) and its psychophysical function (S/R). Those distance were summed into unidimensional integration (1-d) and combined by root sum of squares for multidimensdional integration (4-d). Linear regression from distances to strawberriness scores gave the variance accounted for by each model.

Results

Overall patterns of cognition

First it should be noted from inspection of all the Figures that there was always effectively zero support ($r^2 < 0.1$) for at least two of the six hypotheses about cognitive processing that were tested on each of the seven ratings. Often less than 15% of the variance in the judgments of overall strawberriness was explained by four or five of the hypotheses. That is, the output from this set of models of cognition was far from randomly distributed among the calculations.

Secondly, both assessors showed evidence of learning. The most successful cognitive model in the first session in either assessor accounted for barely 50% of the variance in the integrative judgment being explained. In later sessions with both assessors, the best model explained over 80% of the variance and reached at least 60% for every judgment. More specific evidence of learning was seen over the four sessions run with assessor B.

Case A (two sessions)

The assesssor who had two sessions gave the terms "sherbet," "leafy," "orange skin" and "buttery" for maltol, the 6-C compound, the ester and diacetyl respectively.

In both sessions, the ratings on those terms (R) operating separately (4-d) accounted for at least half of the variation among samples in the rating of overall strawberriness (Figure 1). This 4-d conceptual model was slightly more successful in the second session. Nevertheless it was overtaken by a much strong effects of undimenional combination of ratings concepts (R 1-d; Figure 1, lower panel). That is, the evidence is this assessor configured the notes under a single concept.

Figure 1 about here

The ratings separately of the strength and the balance of the strawberry aroma threw more light on this overall performamce and its change with experience. In the first seesion, both quantity and quality were domninated by a 4-d process involving the rated conceopts of the notes (Figure 2, top panels of upper and lower pair). However, the ratings of quality of balance of notes were best accounted for by the relation of the odorant to its concept (S/R model, 1st Session Quality). Also strength gave signs of 1-d configuring.

Figure 2 about here

The second session showed a striking differentation in processing between strength and balance. Strength went heavily over to 4-d control by the concentrations of the odorants in the test mixtures (S model, Figure 2, second panel). The 1-d modelling emerged clearly but in the ratios of quality of balance, especially among the concepts (R, bottom panel of Figure 2). This explained the strong processing of overall strawberry aroma by a 1-d conceptual model (Figure 1, bottom panel).

Case B (four sessions)

The terms used by the other assessor for the odorants were sweet, leafy, fruity and creamy. This assessor also started with the 4-d conceptual (R) process accounting for overall strawberriness and maintained it over the four sessions, very strongly in the fourth.[1] In this case, however, 4-d stimulation (S) processing and 1-d conceptual (R) and descriptive (S/R) processing were almost as well evidenced in the first session. Strength accounted for the unidimensional integration and quality showed 4-d processing, albeit descriptive, rather than conceptual or stimulatory as overall.

Subsequent sessions saw 4-d processing come to predominate in both strength and balance, and conceptual too as in overall judgments, with some hint of descrpitive processing. Therefore this assessor learnt to use the concepts that related to the odorants, rather than following their stimulation directly.

Discussion

These two cases of assessment of a simulated strawberry aroma suffice to show how causal processes in the performance of olfactory perception can be characterised using the simplest psychophysical theory yet constructed. Of course, no general conclusions can be drawn from this design of experiment about the aroma of strawberries or these individuals' cognitive processes, let alone about olfaction or cognition in general.

The research project yielding these data was intended to test the feasibility of studying interactions between discriminal processes within well learnt sensory configurations, at a time when the approach had been used only on mixtures of up to four tastants in a familiar beverage (Booth & Freeman, 1993). The research grant proposal had been based on the availability of the unusual instance of only four odorants that in the right proportions have a smell remarkably like that of fresh strawberries. The limited number of hypothetical cognitive processes that could be calculated at that time yielded remarkably precise diagnoses, some reported at earlier meetings (Booth *et al*., 1993; Kendal-Reed & Booth, 1992a,b) and those above. Hence the approach was not limited to the special case of taste as was supposed (Lockhead, 1994).

In any case, the earlier work on single sensory features configurated into the familiar context of a food or drink had involved other senses, including sight (Conner *et al*., 1994). The first version of multi-feature approach was applied also to tactile features of dairy cream (Richardson & Booth, 1993; Booth, 2005), and a later version to auditory and tactile textures of biscuits (Mobini, Platts & Booth, under review). Even semantic features can be discrimination-scaled and interacted with sensory features (Freeman & Booth, 2010). So there is no reason to expect any limit on the sensory scope of normed discriminations.

An obvious extension of this early work on tastants and on odorants was to learnt configural norms of taste and odour. Such work was prevented on the grounds that sensory description is needed. Yet if there had been no data on the odorants' notes in the present experiment, the stimulation-driven (S) processes could still have been calculated. Indeed, they were observed in both of these assessors. Rated satiety to olfactory and visceral sensing met the criterion for learnt configurating (Booth *et al*., 1994). Configural integration of odour with taste occurs with sweetness at least (Prescott & Murphy, 2009). Normed discrimination analysis of performance before and after learning could advance associative theory in ways that categorical stimuli cannot do without generalisation gradients (Pearce, 1994).

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Captions to Figures

Figure 1. Overall similarity to the aroma of fresh strawberries accounted for (bivariate linear regression variance) by four- or one-dimensional stimulatory (S), response conceptual (R) or descriptive (S/R) processing in Assessor A in two separate sessions of evaluating the quaternary mixtures.

Figure 2. Variance accounted for in strength and quality (balance) of the aroma of fresh strawberries rated after overall similarity in each mixture (Figure 1) by four- or one-dimensional combinations of stimulatory (S), response conceptual (R) or descriptive (S/R) processing in Assessor A.

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[Figure 3. Variance accounted for in Assessor B's ratings of overall similarity to and strength and quality of strawberry aroma by stimulatory (S), conceptual (R) or descriptive (S/R) mentation on separate dimensions (4-d) or the same dimension (1-d).]

Figure 1. Case A, Sessions 1 and 2, overall strawberriness.
from SigmaPlot files in <u>one</u>-column layout for publication (close gap between each panel and its title).

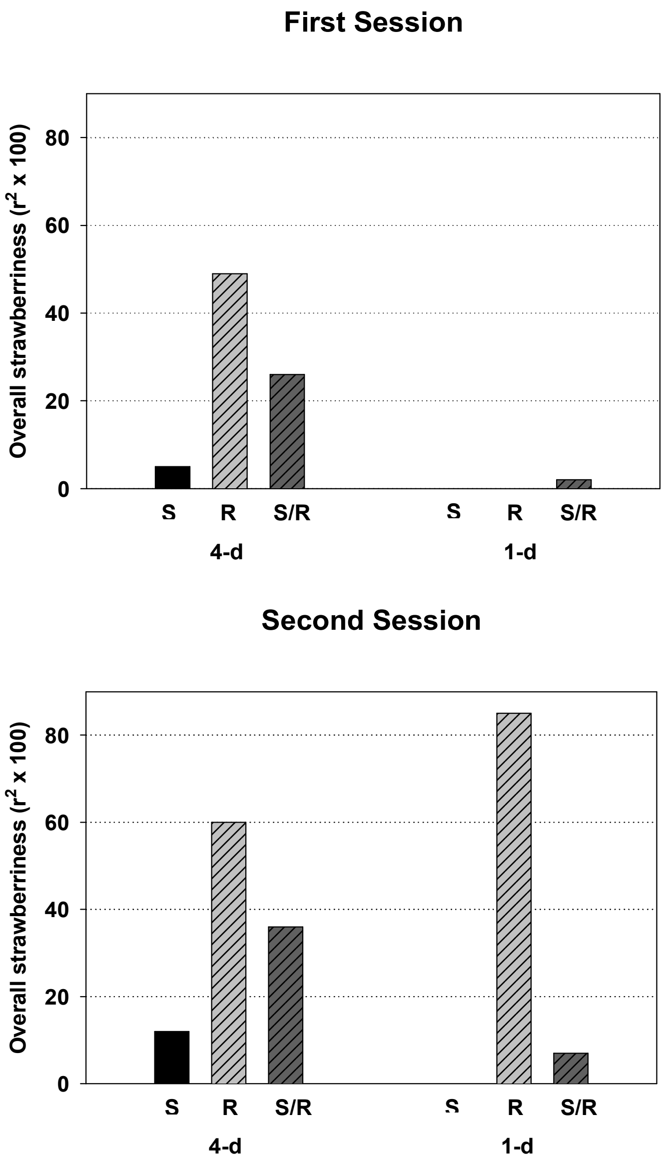

Figure 2. Assessor A, Sessions 1 and 2: strength and quality of strawberry aroma

from SigmaPlot files

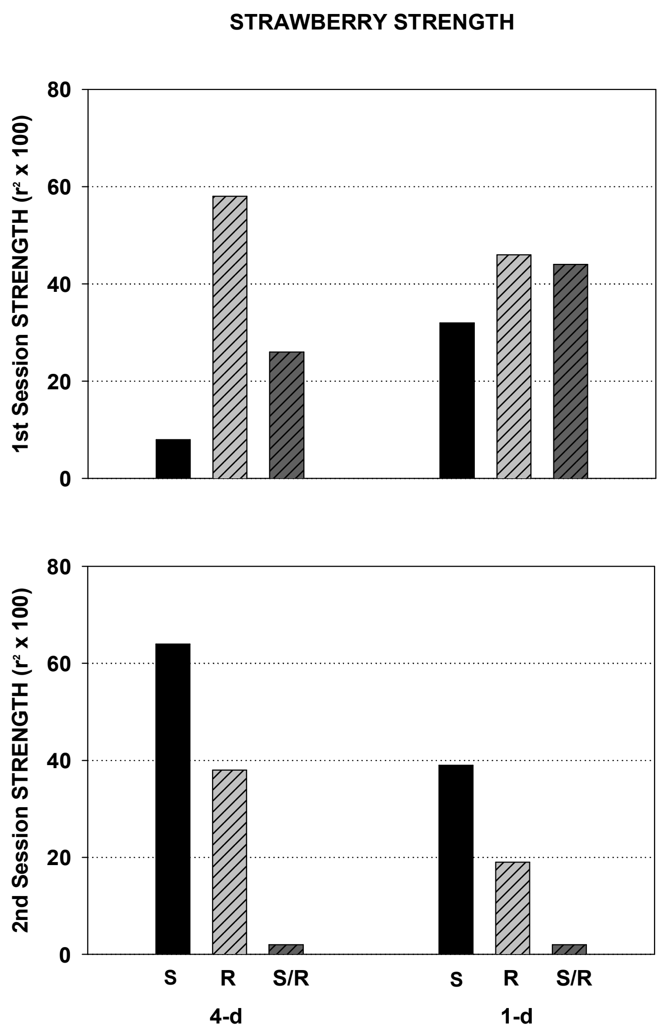

Figure 2 CONTINUED below

Fig. 2 (cont'd). Case A Quality of strawberry aroma – *to go immediately* *__BELOW__* *Fig 2 Strength*

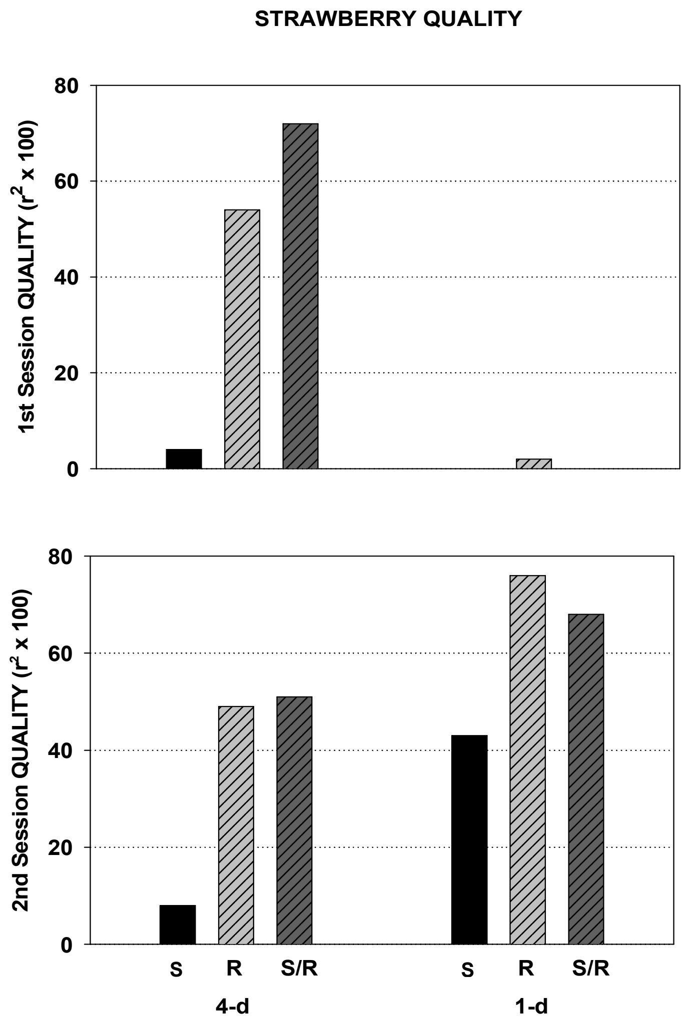

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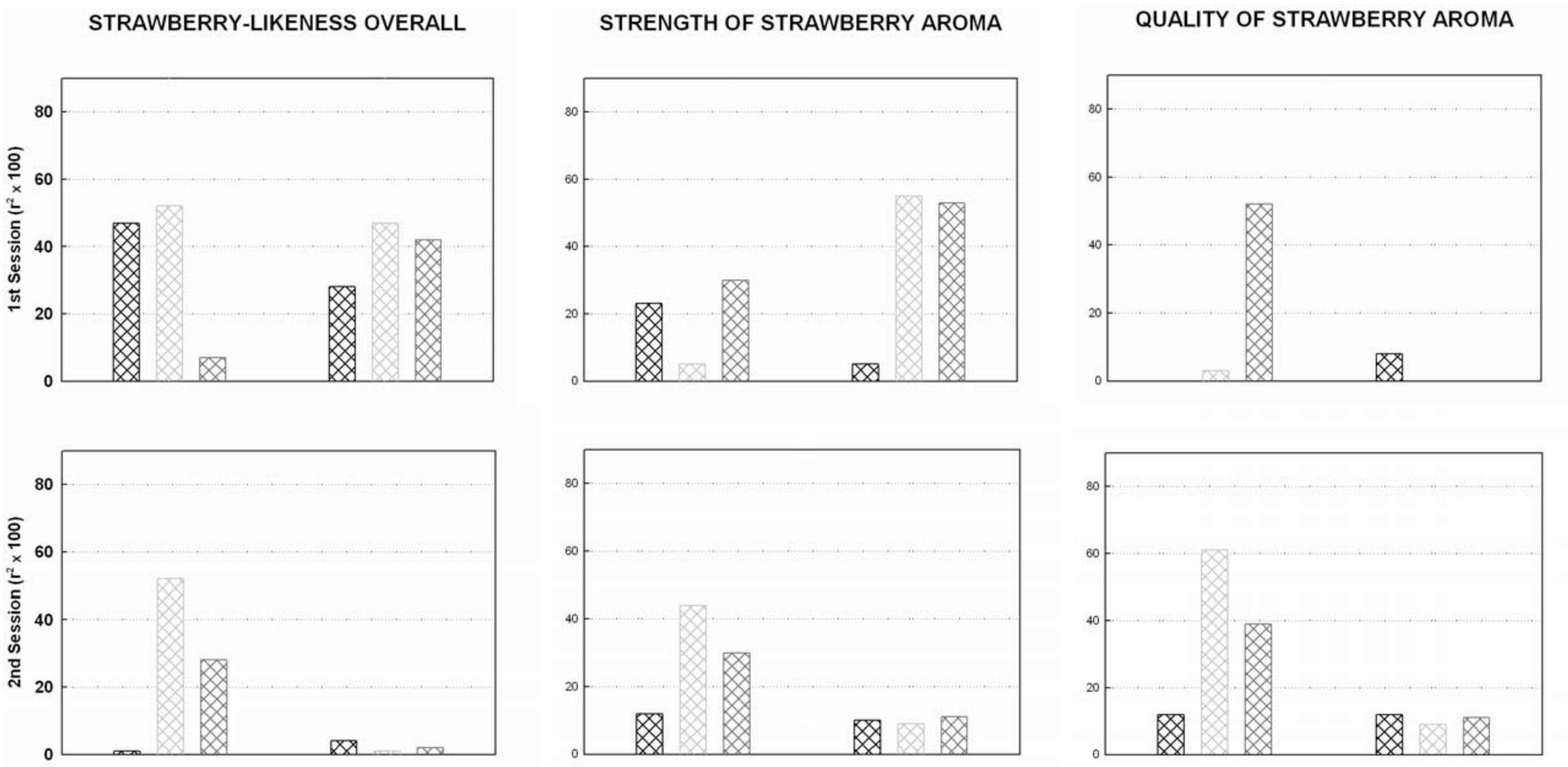
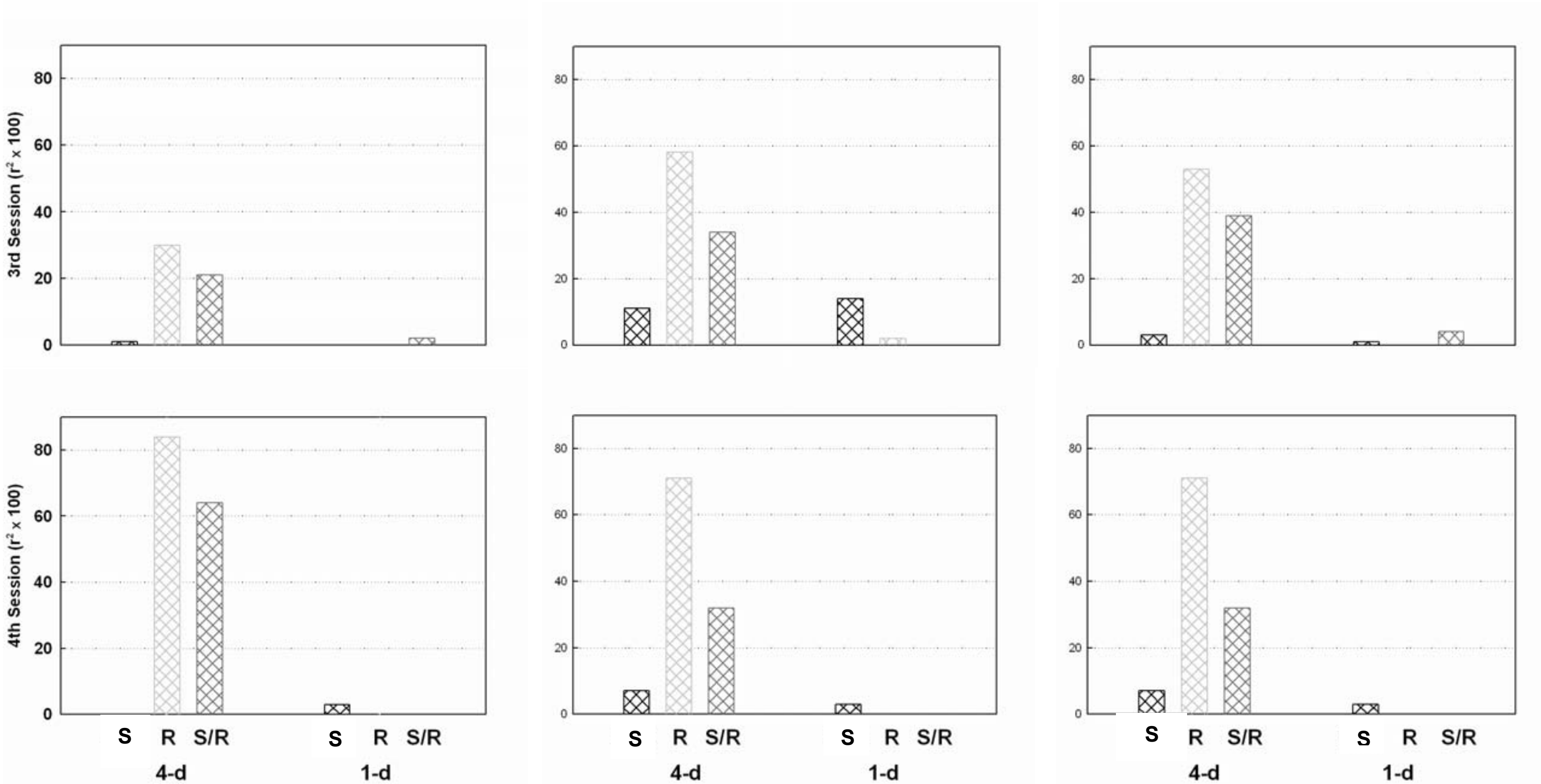
Figure 3. Assessor B, Sessions 1-4. Processes determining Overall-similarity, Strength and Quality ratings *(TIFF files, on 2pp of MS)*





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