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Understanding Creaminess Perception of Dairy Products Using Free-Choice Profiling and Genetic Responsivity to 6-*n*-Propylthiouracil

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Abstract

Flavor and texture contribute to the perception of creaminess in dairy products, but the nature of this interaction is not well understood. Previous studies on the genetic ability to perceive the bitter compound 6-*n*-propylthiouracil (PROP) reveal the existence of individual differences in creaminess perception. The objective of the present study was to use PROP-classified subjects to gain insight into this individual variation to better understand the cues for creaminess in dairy products, and to ascertain the contributions of flavor and texture to the integrated perception of creaminess. Ten nontasters and 10 supertasters of PROP participated in the study. Subjects evaluated nine commercial dairy products using Free-Choice Profiling (FCP), a type of descriptive analysis that allows subjects to rate products on individual lists of descriptors. Generalized Procrustes Analysis was used to develop separate consensus spaces for nontasters and supertasters. The models for both groups accounted for ~54% of the variance in the data and were resolved in two dimensions (a dairy flavor/texture axis and a sweet–sour continuum). The products were arranged in a similar pattern along the dimensions in both models. However, nontasters used a limited number of simple terms (sour, sweet, milky and mouthcoating) to describe the products, whereas supertasters used a more complex vocabulary (rich, buttery, creamy, light, grainy, gritty and sandy). The model for nontasters gave equal weight to the sweet–sour and dairy flavor/texture dimensions (28 and 26% variance, respectively); whereas, the model for supertasters relied more heavily on the dairy flavor/texture dimension (34% variance), and less so on the sweet–sour dimension (20% variance). These data suggest that the overall impression of creaminess was similar for nontasters and supertasters, but the cues the two groups used to judge creaminess differed.

Key words: creaminess perception, 6-*n*-propylthiouracil, Free-choice Profiling

Introduction

Fat content contributes to the perception of creaminess in dairy products. Creaminess is a highly integrated and complex perception that encompasses both flavor and texture sensations (Mela, 1988). A fundamental understanding of creaminess perception could be obtained by decomposing creaminess into its underlying sensory components. Accomplishing this task has been difficult since changes in stimulus fat content simultaneously affect the texture of dairy products (Mela, 1988; Li *et al*., 1997; Richardson-Harman *et al*., 2000), as well as the flavor release (Mela, 1988; Li *et al*., 1997; Richardson-Harman *et al*., 2000).

The texture of dairy products can be ascertained from tactile sensations produced in the mouth (Mela, 1988). These attributes include slipperiness, greasy mouthfeel (Tuorila, 1986), creaminess and residual mouthfeel (Bom Frost *et al*., 2001). Kokini and Cussler demonstrated that texture perception in the mouth could be modeled as a mathematical function of thickness and smoothness (Kokini and Cussler, 1983). In fluid dairy products, the presence of small, even-sized fat globules coupled with adequate viscosity enhances the perception of creaminess (Richardson *et al*., 1993).

The contribution of milk fat to perceived fat content and creaminess is less well understood. Mela demonstrated equivalent results when the perceived fat content of fluid dairy products was assessed with and without nose clips (Mela, 1988), suggesting that flavor cues made little or no contribution to the overall assessment of creaminess. However, Li *et al*. showed that altering the fat content of ice creams modulated the pattern of release of flavor compounds (Li *et al*., 1997). The latter findings are consistent with a large body of work suggesting that fat content affects the intensity, duration and balance of flavors present in many foods (Lucca and Tepper, 1995), including dairy products (Elmore *et al*., 1999).

Other experiments have shown that supplementing dairy products with added flavor enhances creaminess perception. For example, Lawless and Clark showed that when vanilla flavor was added to 1% fat milk, the perception of fat and creaminess increased (Lawless and Clark, 1992). In another study, adding dairy flavor to milk model systems ranging from 0 to 10% fat resulted in greater perceived fat content and creaminess in the higher fat samples (Tepper and Kuang, 1996). Therefore, flavor may make a more significant contribution to the perception of creaminess in foods than some data seem to suggest.

Creaminess is a critical sensory attribute for consumer acceptance of products (Daget *et al.*, 1987; Richardson-Harman *et al.*, 2000). However, consumers use the term creaminess interchangeably to describe flavor and textural perceptions in dairy products, most often not distinguishing between them. Thus, creaminess may be a difficult precept to quantify if individuals are using the term as a flavor descriptor, a texture descriptor or as an integrative perception of both characteristics. It is possible that individuals may vary in their sensory acuity for specific flavor and/or texture attributes that impart creaminess in dairy products. As a consequence, individuals might utilize proportionately greater or fewer flavor cues, relative to texture, to judge creaminess in these foods. Understanding these sources of variation may provide insight into individual differences in creaminess perception as well as the underlying dimensions of creaminess perception.

Individual differences in perception have been observed among individuals classified by PROP taster status (Tepper and Nurse, 1997). PROP (6-*n*-propylthiouracil) is a bitter tasting compound, the perception of which is genetically determined (Bartoshuk *et al.*, 1994). Individuals can be grouped as nontasters, medium tasters and supertasters based upon their sensitivity to PROP (Bartoshuk *et al.*, 1994). Tasters (medium and supertasters) are more sensitive than nontasters to the bitterness of caffeine, and to the sweetness of sucrose and some artificial sweeteners (Bartoshuk *et al.*, 1994; Lucchina *et al.*, 1998). Differences among taster groups have also been observed for trigeminal sensations, including irritation from alcohol and capsaicin, the burn of chili peppers (Karrer and Bartoshuk, 1991; Bartoshuk *et al.*, 1994; Tepper and Nurse, 1997; Lucchina *et al.*, 1998).

Some studies have also shown that PROP tasters are also more sensitive to fat (Tepper, 1998). Tepper and Nurse (Tepper and Nurse, 1997) found that medium tasters and supertasters were able to discriminate between 10 and 40% fat salad dressings, whereas nontasters assessed the fat content of the samples as equivalent. Duffy *et al.* investigated creaminess perception in fluid dairy products and found that PROP supertasters gave the highest ratings of creaminess to milk products with fat contents ranging from 11.5% to 54% (Duffy *et al.*, 1996). It has been hypothesized that PROP tasters are more responsive to oral texture because they perceive more tactile sensations on the tongue (Duffy *et al.*, 1996). Other studies have not reported taster-group differences in creaminess perception with sweetened milk mixtures (Drewnowski *et al.*, 1998) or flavored puddings and dairy drinks (Yackinous and Guinard, 2001) formulated in the laboratory. These data raise doubts about the role of PROP status in the perception of more complex dairy foods. Further investigation of this issue was a primary aim of the present study.

Conventional descriptive analysis has been used to characterize the texture attributes of fluid dairy products (Tuorila, 1986; Bom Frost *et al.*, 2001). However, descriptive analysis forces all subjects to utilize the same terminology and define each of these terms in the same way, ignoring individual differences in perception. Free-Choice Profiling (FCP) differs from conventional descriptive analysis in that each subject describes the perceived qualities of samples using his or her own individual list of terms, rather than the group lexicon (Oreskovich *et al.*, 1991; Heymann, 1994). Few limitations are put upon subjects in FCP, allowing them freedom and flexibility to describe individual perceptions of products. Li *et al.* used FCP to study vanilla ice cream varying in fat content and found that subjects used a variety of both flavor and textural attributes to describe the samples (Li *et al.*, 1997). If individuals use different criteria to define and assess creaminess, the use of FCP might help to expose these differences.

The present study utilizes FCP with individuals classified by PROP taster status. This approach was intended to gain insight into individual differences in perception to better understand the cues for creaminess and assess the contribution of flavor and texture to the overall perception of creaminess. It was hypothesized that supertasters will perceive more creaminess in dairy products, as compared with nontasters, and that the perception of creaminess would relate specifically to the textural components of these foods. Previous research on creaminess perception has utilized model systems, which are not fully representative of actual food products (Daget *et al.*, 1987; Tepper and Kuang, 1996; Richardson-Harman *et al.*, 2000). A range of commercially available dairy products was used in the present study to better understand these relationships in real foods.

Materials and methods

Subject screening and selection

PROP screening

Seventy-six adults of the International Flavors and Fragrances, Inc. Creative Center, South Brunswick, NJ were previously screened for their PROP sensitivity. These individuals comprised a subject pool from which participants in the current study were drawn. The pool consisted of 37 females and 39 males with a mean age of 38.8 ± 8.0 (mean ± SD) (range 21–60 years). Participants were healthy individuals from various technical backgrounds including creation and application of flavors and were free of oral or nasal illness at the time of the study.

Subjects were classified for PROP taster status utilizing the one-solution method (Tepper *et al.*, 2001). The method involves obtaining suprathreshold ratings for 0.32 mmol/l PROP (Aldrich Chemical, Milwaukee, WI) and 0.1 mol/l NaCl (Fischer Scientific, Fairlawn, NJ). Both solutions were prepared with room temperature spring water, however the PROP solution required mild heat to dissolve into solution.

To screen for PROP taster status, two sessions were conducted on separate days. On each day, subjects were presented with 10 ml of 0.1 mol/l NaCl solution followed by 10 ml of 0.32 mmol/l PROP solution in three-digit coded sample cups. Evaluations were conducted in individual testing booths equipped with white lighting. Using Compusense version 4.0 direct data entry system (Guelph, Ontario), subjects rated the intensity of the solutions using the Labeled Magnitude Scale (LMS scale). The LMS scale is considered quasilogarithmic with label descriptors similar to magnitude estimation (Green *et al.*, 1993, 1996). The end descriptors included *barely detectable* and *strongest imaginable*. Subjects were instructed to taste and rate the samples relative to oral stimuli experienced in everyday life. Subjects rinsed their mouths with water prior to tasting each sample. Then, they put the entire 10 ml sample in their mouth, rated the intensity of the stimulus and expectorated. There was a 1 min break between the NaCl and PROP evaluations. Replicate evaluations for the solutions were obtained, separated by at least 24 h but no more than 5 days. All participants signed an informed consent form prior to participating in the screening.

For each subject, the average of the two PROP intensity ratings was calculated. Three taster groups were identified using K-means cluster analysis (JMP version 4.05, SAS Institute, Cary, NC). These grouping were used to establish numerical cutoffs for PROP. The cutoffs were confirmed by calculating the 95% confidence interval around the mean for each of the groups, according to the classification method developed by Tepper *et al.* (Tepper *et al.*, 2001). Mean NaCl ratings for each group were also determined.

Among the 76 subjects screened, individuals whose ratings for PROP intensity were <11.5 on the LMS were classified as nontasters, those whose ratings were between 11.5 and 61 were classified as medium tasters, and those whose ratings were >61 were classified as supertasters (see Figure 1). Occasionally, when a borderline rating for PROP was given by a subject, the rating was compared with the rating for NaCl to help clarify group assignment (Tepper *et al.*, 2001). For example, if a subject gave PROP a borderline rating of 61, but he/she gave NaCl a much lower rating, this individual would be classified as a supertaster. Conversely, if the subject gave both PROP and NaCl a borderline rating of 61, the individual would be classified as a medium taster. Twenty-one nontasters, 28 medium tasters and 27 supertasters were identified. Follow-up analyses also revealed that

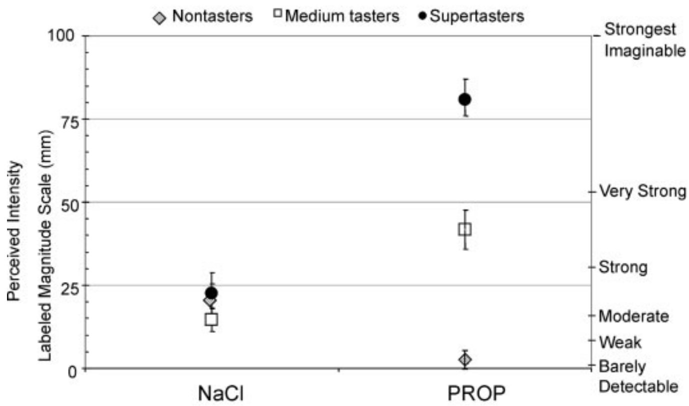

Figure 1 Classification of a pool of 76 subjects by PROP taster status. Subjects rated the intensity 0.1 mol/l NaCl and 0.32 mmol/l PROP using the Labeled Magnitude Scale (LMS). Mean values shown (±95% confidence interval). Taster groups were identified by calculating the 95% confidence interval around the group means for PROP intensity. The cutoff values (on the LMS) were: <11.5 for nontasters (*n* = 21), 11.5–61 for Medium tasters (*n* = 28) and >61.5 for supertasters (*n* = 27). Ten nontasters and 10 supertasters were selected from the subject pool to participate in the FCP study.

the NaCl mean intensity ratings were not significantly different among the three taster groups ($P = 0.20$), which has been observed in previous studies (Tepper and Nurse, 1997; Tepper *et al.*, 2001; Tepper and Ullrich, 2002; Zhao *et al.*, 2003).

FCP subjects

Ten nontasters and 10 supertasters were selected from this subject pool to participate in the FCP study. There were five females and five males in each PROP taster group. Across the groups, subjects were matched as closely as possible for age, height and weight. All participants were classified as unrestrained eaters using a 10 question abbreviated version of the Three-Factor Eating Questionnaire (Tepper *et al.*, 1997). All subjects were considered semi-trained, as they had frequently participated in other sensory evaluations with a variety of food products, and were familiar with tasting and evaluating samples. Previously, Heymann suggested that FCP should be used with subjects with prior experience in sensory methods, as 'sensory naive' subjects did not produce consistent results (Heymann, 1994).

Taste stimuli

The nine foods used for the FCP study represented a range of market dairy products. They were chosen based upon their fat content, viscosity, sweetness and flavor (see Table 1). Many of the same foods were used in a previous study by Kokini and Cussler, which investigated the texture of dairy products (Kokini and Cussler, 1983). All products were obtained from local New Jersey grocery stores and served at their customary refrigerated temperature, except the vanilla ice cream, which was served frozen, and the sweetened condensed milk, which was served at room temperature.

Table 1 Sample descriptions of nine dairy products

Food	Abbreviated name	Fat content (%)	Viscosity	Sweet/non-sweet	Brand name
Vanilla yogurt	Van Yog	1.5	semi-solid	sweet	Dannon Vanilla Lowfat Yogurt Grade A 1.5% milkfat, Dannon Company, Inc., Tarrytown, NY
Sweetened condensed milk	Swt Cond Mlk	7.5	viscous fluid	sweet	Borden, Eagle Brand, Columbus, OH
Whole milk	Whole Mlk	3.5	fluid	non-sweet	Lehigh Valley Dairies, Lansdale, PA
Skim milk	Skim Mlk	0	fluid	non-sweet	Lehigh Valley Dairies, Lansdale, PA
Light cream	Lt Cream	36	fluid	non-sweet	Lehigh Valley Dairies, Lansdale, PA
Cream cheese	Cream Cheese	35	semi-solid	non-sweet	Philadelphia Original Cream Cheese, Kraft Foods, Glenview, IL
Vanilla ice cream	Van Ice Cream	13	frozen	sweet	Breyer's Natural Vanilla Ice Cream, Good Humor-Breyer's Ice Cream, Green Bay, WI
Whipped light cream	Wpd Cream	25	foam	sweet	Reddi Whip Original Ultra Pasteurized Sweetened Whipped Light Cream, Beatrice Foods, Indianapolis, IN
Sour cream	Sour Cream	18	semi-solid	non-sweet	Breakstone's Sour Cream Grade A Pasteurized Homogenized, Kraft Foods, Inc., Glenview, IL

Procedure

The FCP study started with two orientation sessions. Each subject completed the series individually. In the orientation sessions, each subject tasted the sample set and developed his or her own list of terms to describe the samples. Subjects were prompted to generate words to fully describe the appearance, taste/flavor and mouthfeel/texture of the products. The name of the attribute could be anything that the subject desired; however the subject had to be able to use the attribute consistently across all products. Subjects were informed that they would use their personal list of attributes in future tasting sessions.

There were four evaluation sessions; five samples were served in the first session followed by the remaining four samples in the second session. The final two sessions included a replicate evaluation of all products. Approximately 2 oz. samples were served in a counterbalanced order in 4 oz. soufflé cups under white lighting. Subjects rated the terms on a 15 cm line scale with the anchors of *none at all* to *extremely strong* using Compusense version 4.0 direct data entry software (Guelph, Ontario, Canada).

Analysis

The total and average number of terms used by nontasters and supertasters to describe the samples were separately tallied by appearance, flavor and texture attributes. Group differences were analyzed by Analysis of Variance (ANOVA).

Generalized Procrustes Analysis (GPA) was then used to condense the individual evaluations into a consensus space (Oreskovich *et al*., 1991). Individual attribute means cannot be calculated, because the terms are not standardized across subjects. Interpretation of the GPA data was obtained by examining the position of the foods and attributes in the *n*-dimensional space. Separate *n*-dimensional spaces were calculated for nontasters and supertasters.

The GPA was performed with the statistical analysis software Senstools (OP&V Research, Guelph, Ontario, Canada). Eigenvalues and variance for each dimension were computed using the Procrustes Analysis of Variance (PANOVA), which demonstrates the relative importance of each dimension to the model. Then, a permutation test was conducted on the total variance accounted for from the PANOVA, to indicate if a true consensus space among subjects was obtained.

The final output of the GPA analysis is a visualization of the foods and attributes in an *n*-dimensional space. To interpret the spaces, three pieces of information are assimilated including (i) the product orientations in *n*-dimensional space, (ii) the dimension loadings (how much each dimension captures the total variance), and (iii) how the attributes relate to the dimensions. Significant relationships between attributes and dimensions were identified by correlations >0.5 on the main axis and <0.3 on all other axes.

Results

Lexicon

The total number of terms used by individual subjects to describe the products ranged from 14 to 53. PROP supertasters and nontasters did not differ in the average number of terms used ($P = 0.46$). The terms were separately tallied by appearance, flavor/taste and mouthfeel/texture characteristics (see Table 2). The terms sweet, sour, vanilla, creamy, smooth and thick were used by most of the subjects in both the nontaster and supertaster groups, however supertasters tended to use different mouthfeel/texture terms than nontasters.

Generalized Procrustes Analysis

GPA analysis was conducted for appearance, flavor and texture attributes. Separate analyses were performed for the nontaster and supertaster groups. The analyses revealed that both groups used appearance attributes similarly in their consensus spaces. Therefore, to better understand the contribution of oral sensory perception to these products, the appearance attributes were removed from subsequent analyses. The following section describes models based on the flavor and texture evaluations the samples.

GPA revealed that the data from each taster group was resolved in three major dimensions, each with eigenvalues greater than one. The total variance accounted for in three dimensions was 77.1% for the nontasters and 75.2% for the supertasters. These values were significantly different from chance as determined by the permutation test, indicating that a true consensus space was achieved ($P \leq 0.05$). Dimensions 1 and 2 accounted for the majority of the variance in the models, and together were also significantly different from chance by the permutation test ($P \leq 0.05$). Dimension 3 was difficult to interpret due to a limited number of terms loading on the dimension. Therefore, the final analyses focused on the solution in two dimensions.

For both the nontasters and supertasters, the total variance accounted for in the two-dimensional models was ~54%. For nontasters, the percent of variance accounted for in Dimensions 1 and 2 were approximately equal (28 and 26%, respectively). For supertasters, Dimension 1 accounted for a higher percent of variance in the model (34%) as compared to Dimension 2 (20%).

The two-dimensional space for nontasters is described in Figure 2. The subjects' attribute labels are shown in italics. For nontasters, Dimension 1 was described as a continuum from *sweet* taste/flavor to *sour* and *buttermilk* taste/flavor. Dimension 2 was described by the terms *milky* and *bland* taste/flavor on one end, to *sweet* taste/flavor and *mouthcoating*, *thick* mouthfeel/texture on the other end.

For supertasters (Figure 3), the two dimensions are rotated. Dimension 1 reflected a gradation of dairy flavor and texture terms. The terms *rich*, *buttery*, *creamy* taste/flavor and *creamy*, *thick*, *coating*, *heavy* mouthfeel/texture described one end of the continuum. The other end of the continuum included *watery*, *light* mouthfeel/texture and *bland*, *watery*, *milky/dairy* taste/flavor. Dimension 2 consisted of basic tastes plus textural terms, such that *sour* and *salty* taste/flavor were contrasted with *grainy*, *gritty*, *sandy* mouthfeel/texture. The latter textural terms were absent from the nontasters basic taste dimension.

The figures also show the relationship between the products in the two-dimensional spaces. The relative positions of the foods on the dimensions were similar for nontasters and supertasters. The foods that loaded on the sweet–sour continuum (Dimension 1 for nontasters and Dimension 2 for supertasters) included sour cream, cream cheese and vanilla ice cream. Sweetened condensed milk, whole milk and skim milk loaded high on the dairy flavor/texture dimension (Dimension 2 for nontasters and Dimension 1 for supertasters). For supertasters and nontasters, the foods maintained the same position relative to the major axis, but the order of the dimensions was reversed.

Table 2 Attribute labels used by nontasters and supertasters in FCP

Nontasters		Supertasters	
Attribute	No. of responses	Attribute	No. of responses
	Appearance		+
White	7	Thick	7
Smooth	5	Watery	6
Thick	5	White	6
Liquid	4	Creamy	4
Opaque	4	Fluffy	4
		Smooth	4
		Yellow	4
	Taste/flavor		
Sweet	10	Sweet	10
Sour	8	Sour	9
Vanilla	7	Vanilla	8
Creamy	7	Cream	7
Dairy	6	Salty	7
Milky	6	Butter	5
Buttery	4	Bitter	4
Caramel	4	Creamy	4
Salty	4	Dairy	4
	Mouthfeel/texture		
Smooth	8	Smooth	8
Creamy	7	Thick	7
Thick	6	Creamy	6
Fatty	4	Grainy	6
Light	4	Gritty	4
Mouthcoating	4	Heavy	4
Sticky	4	Watery	4

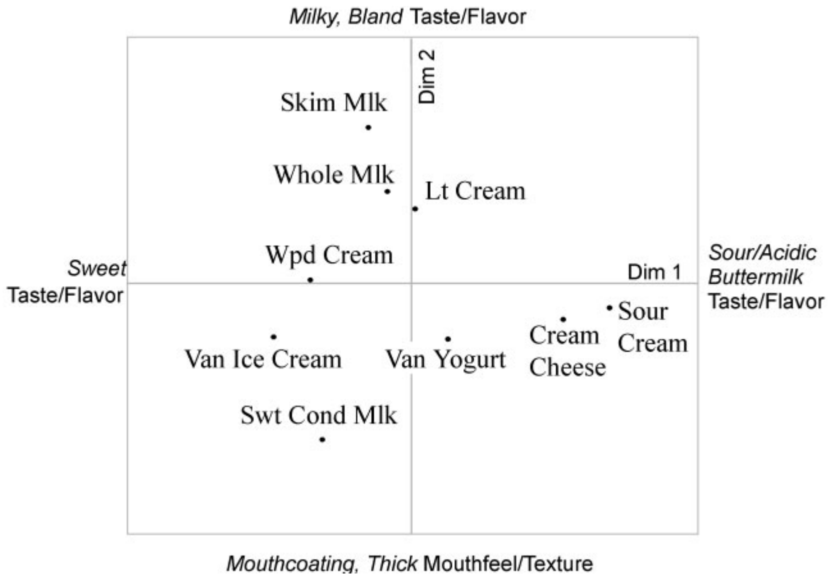

Figure 2 Generalized Procrustes Analysis for nine dairy products by 10 nontasters: dimension 1 horizontal axis (28.6% variance) versus dimension 2 vertical axis (26.3% variance) with total variance accounted for of 54.9%.

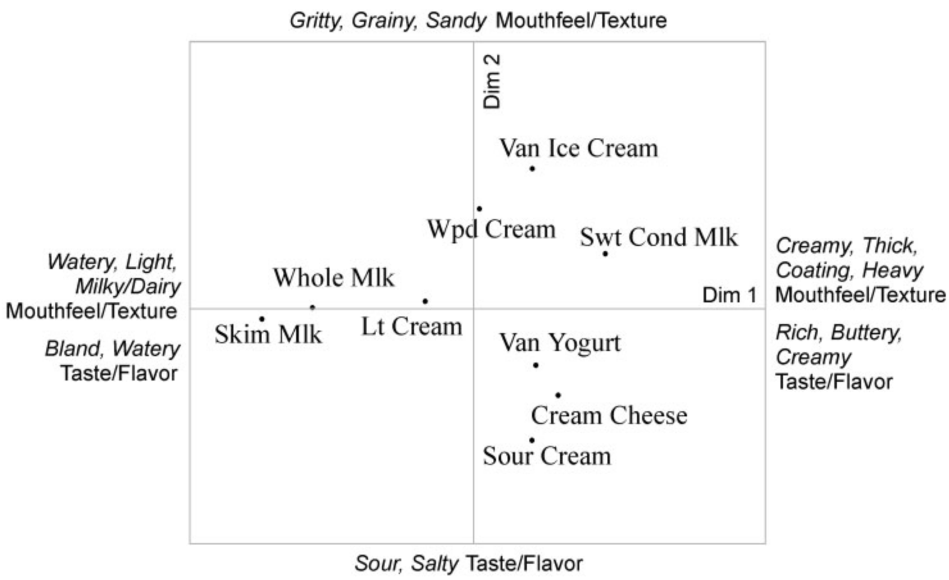

Figure 3 Generalized Procrustes Analysis for nine dairy products by 10 supertasters: dimension 1 horizontal axis (34.3% variance) versus dimension 2 vertical axis (19.9% variance) with total variance accounted for of 54.2%.

For both taster groups, the dimensions of the model explain the major characteristics of dairy products. However, supertasters used more terms overall to describe their perceptions, and also used a greater number of attributes related to texture.

Discussion

The objectives of this study were to gain insight into individual differences in perception to better understand the cues for creaminess and to assess the contribution of flavor and texture to the overall perception of creaminess. These goals were accomplished by investigating individual descriptions and consensus spaces of dairy products from FCP and by studying the group effects of PROP-classified subjects.

Overall, there were a number of similarities in the perceptual spaces of nontasters and supertasters. The models for both groups were resolved in two dimensions and were described by a dairy flavor/texture axis and a sweet–sour axis. Both models accounted for ~54% of the variance in the data. Also, the products were arranged in a similar pattern along the dimensions in the models for both groups. Thus, both groups described their perceptions of the products using a combination of dairy flavor and texture terms plus basic tastes.

There were also striking differences in certain features of the models of nontasters and supertasters. Nontasters used a limited number of simple terms such as sour, sweet, milky and mouthcoating to describe the products. In contrast, supertasters used a more complex vocabulary, including terms such as rich, buttery, creamy, light, grainy, gritty and sandy. The model for nontasters gave equal weight to the sweet–sour and dairy flavor/texture dimensions (28% and 26% variance, respectively); whereas, the model for supertasters relied more heavily on the dairy flavor/texture dimension (34% variance), and less so on the sweet–sour dimension (21% variance). Thus, although the perceptual spaces for creaminess were similar for nontasters and supertasters, the cues used to judge creaminess differed for the two groups.

A fundamental question raised by this research is whether supertasters perceive more creaminess *intensity* in dairy products. Studies have investigated this question but have failed to come to come to a consensus on the issue. Duffy *et al*. (Duffy *et al*., 1996) reported that PROP tasters perceived more creaminess intensity in high-fat milk products (11.5–54% fat). Other research found no differences in creaminess and/or fattiness perception among PROP taster groups for sweet-fat milk mixtures (Drewnowski *et al*., 1998) or chocolate dairy drinks and vanilla puddings varying in flavor and fat content (Yackinous and Guinard, 2001). In contrast, Tepper *et al.* (Tepper *et al*., 2002) recently reported a moderate effect of PROP status on judgements of creaminess intensity in sweetened and unsweetened milks. Creaminess ratings of milks with increasing fat content rose more rapidly for supertasters than for medium tasters and nontasters. Similar results were obtained for sweetened and unsweetened samples. Although the present study did not directly compare intensity judgments across taster groups, the GPA models revealed qualitative differences in the use of descriptive terms for creaminess by nontasters and supertasters. Thus, current evidence supports a role for PROP status in the perception creaminess in dairy products, but the magnitude of this effect remains controversial.

Whatever advantage PROP tasters might have in perceiving creaminess may be due to greater acuity of oral texture sensations arising from variation in tongue anatomy (Bartoshuk *et al*., 1994; Duffy *et al*., 1996; Tepper and Nurse, 1997). Supertasters have more taste papillae innervated by trigeminal and other nerve fibers, which may produce a greater somatosensory sensation on the tongue. As expected, supertasters in the present study utilized more textural terms to describe the products including those related to creaminess, heaviness and particulates. An unexpected finding was that supertasters also employed more flavor terms to describe the products. This finding raises the intriguing possibility that flavor perception could also vary with PROP taster status. Support for this idea comes from a recent study showing that PROP supertasters have a lower olfactory threshold than nontasters for diacetyl, a butter-type flavor found in many dairy products (Yackinous and Guinard, 2001). Specific anosmia to this compound has been previously reported, but the nature of the olfactory blindness is poorly understood (Lawless *et al*., 1994). Diacetyl may also elicit pungency or nasal irritation (Arctander, 1994), contributing to the reported differences in olfactory thresholds. Thus, it is possible that PROP taste responsivity plays a role in other sensory systems such as olfaction and nasal pungency. Further investigation of these areas is warranted.

It was initially expected that using FCP would help to deconstruct creaminess into its constituent parts, projecting flavor and texture terms onto separate dimensions of the models. However, the results of the present study did not support this hypothesis. Our results agree with the findings from an earlier study by Li *et al.* on FCP of ice creams (Li *et al*., 1997). In that study, both flavor and texture terms also loaded on the same dimension. Tepper and Kuang (Tepper and Kuang, 1996) used multidimensional scaling to investigate the perception of milk model systems. They found that flavor and texture loaded on separate dimensions of the model. However, two features of the Tepper and Kuang study design might have facilitated this separation. First, fat content and dairy flavor were separately manipulated in the samples. Second, subjects were instructed to rate the degree of difference among sample pairs for specified attributes; they were not free to choose their own descriptors. Thus, the present data support the notion that flavor and texture may be so highly integrated in dairy products that humans do not easily separate these sensations. The exception is descriptive training, which is designed to deconstruct complex sensory stimuli into their component parts (Meilgaard *et al*., 1991).

Theories of flavor interactions may provide insight into the integration of the senses in creaminess perception. Prescott (Prescott, 1999) recently discussed the concept of flavor in terms of a psychological construct produced by odor and taste integration. Implicit in the concept is the idea that odor/taste mixtures are sensed as unique flavor entities rather than as the sum of their individual components. Learning may play a significant role in this interaction, as demonstrated by experiments showing that taste enhancement is more pronounced for flavor–odor pairs that are familiar and typically appear together in foods. A common example is the pairing of strawberry odor with sucrose, which enhances the perceived sweetness of the mixture. The same pairing with peanut butter does not produce this effect (Frank and Byram, 1988). This concept might also apply to creaminess perception, whereby the pairing of an appropriate flavor with a dairy base enhances the overall creaminess impression. Experiments by Lawless and Clark (Lawless and Clark, 1992) and Tepper and Kuang (Tepper and Kuang, 1996) showed that adding vanilla or dairy flavor to milk systems enhanced the creaminess perception.

The milk fat present in dairy products has unique properties as a source of stimulus fat and volatile flavor compounds. Increasing the concentration of fat in a dairy food also enhances the release of other volatile compounds that may already be present, further enhancing the overall creaminess impact. Thus, 'creamy flavor' and 'creamy texture' may be inexorably linked in the experience of the human assessor because they are physically linked in real dairy products. The neural mechanisms that give rise to these individual sensations and the psychophysical processes that integrate them are poorly understood. Elucidation of these mechanisms would improve our understanding of the effects of physical properties on sensory perceptions.

The GPA models developed in the present study captured ~54% of the variance in two dimensions, which is similar to the results reported by Raats and Shepherd (Raats and Shepherd, 1992). In their study, a two-dimensional model was obtained for milks differing in fat content, which accounted for ~57% of the variance in the data. Li *et al.* (Li *et al.*, 1997) captured over 86% of the variance in three dimensions, however their solution was primarily uni-dimensional, as the first dimension describing the fat content of ice creams contributed over 81% of the variance. In the current study, three-dimensional models of these data were studied initially; however, the third dimension was difficult to interpret because few terms loaded on this dimension. Also, the appearance terms were removed from the analyses in an effort to understand how sensations in the mouth rather than visual characteristics contributed to creaminess. Including the appearance evaluations in the analyses increased the percent of variance captured in the models by ~25% for both nontasters and supertasters. However, Gonzalez Vinas *et al.* (Gonzalez Vinas *et al.*, 2000) have argued that in real food products, appearance can be an overwhelming driver of the model minimizing the contributions of flavor and textural assessments of the products. Thus, eliminating the appearance characteristics seemed justified in light of these data.

The present study combined existing sensory techniques in a novel approach to investigate creaminess perception in dairy products. The rationale for selecting these methods bears mentioning, given the current debate surrounding the use of scaling methods (Green *et al.*, 1993; Bartoshuk, 2000; Bartoshuk *et al.*, 2002), particularly as they relate to PROP screening and classification (Tepper *et al.*, 2001; Bartoshuk *et al.*, 2002; Rankin *et al.*, 2003; Zhao *et al.*, 2003). PROP screening in the present study followed the methodology of Tepper *et al.* (Tepper *et al.*, 2001), which utilizes the LMS. This method is valid as compared with an accepted procedure (Bartoshuk *et al.*, 1994) and has high test–retest reliability as reported by Tepper *et al.* and Rankin *et al.* (Tepper *et al.*, 2001; Rankin *et al.*, 2003). Group assignments in this method depend primarily on numerical cutoff scores for PROP taste intensity; NaCl ratings are used to clarify group assignment when borderline ratings are given [see Tepper *et al.* (Tepper *et al.*, 2001) for a full explanation of these procedures]. The validity of using NaCl as a reference standard has been called into question on the basis of data reported by Pruntkin *et al.* (Pruntkin *et al.*, 2000) who found that intensity ratings for NaCl varied with PROP status. Also, Prescott *et al.* (Prescott *et al.*, 2001) studied binary mixtures of tastants and found a small but statistically significant increase in saltiness intensity for NaCl/quinine hydrochloride mixtures among supertasters. These data contrast with numerous observations from this laboratory, which show no systematic differences in the intensity of NaCl solutions as a function of taster status (Tepper and Nurse, 1997; Tepper *et al.*, 2001; Tepper and Ullrich, 2002; Zhao *et al.*, 2003). The reasons for this disparity are presently unknown and require further study.

A standard, 15 cm line scale was used to collect ratings for the dairy products in the present study. This scale has a long history of use in descriptive analysis and free-choice profiling (Meilgaard *et al.*, 1991) and permitted the models obtained in this study to be directly compared with data from other FCP studies on dairy products. Research by Bartoshuk and colleagues (Bartoshuk, 2000; Bartoshuk *et al.*, 2002) has emphasized the importance of preserving valid across-group comparisons with the use of labeled scales. The generalized LMS (gLMS), a variant of the LMS, seeks to address this issue by placing all stimuli (including gustatory, visual, auditory, etc.) on a common scale with the upper anchor labeled as 'strongest imaginable sensation of any kind'. A universal scale would be desirable on theoretical grounds because it permits subjects the maximum freedom to rate stimuli and would remain independent of context. At present, published data comparing the gLMS to other scales are limited. However, recent work by Horne *et al.* (Horne *et al.*, 2002) found no advantage of the gLMS as compared with the LMS in a study examining sweetness perception in PROP classified individuals. Additional studies should be conducted on the gLMS to establish its true capabilities.

In conclusion, the results of this study showed that the term 'creaminess' may have different meanings to individuals, a finding that could have important implications for language development and utilization of terms in sensory testing. Our findings also showed that characterizing subjects by PROP status was an effective tool for systematically studying individual differences in perception that are biologically mediated. Previously, this variation has been attributed to experimental 'noise' and differences in methodology. Finally, it is important to determine if the results obtained here are relevant to consumer perception and acceptance of products. Future studies will address this topic.

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