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The development of a perceived satiety index for military rations

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Abstract

Studies were conducted to index the perceived satiety value of a variety of military ration items, to assess the relationship of the food's nutrient composition, physical, and sensory properties to satiety, and to determine the ability of the sum of the satiety indices for individual meal components to predict total meal satiety.

Equicaloric 300 kcal portions of 17 common military ration items and two commercial food items were tested. Satiety measures were obtained before consumption, immediately after consumption and every 15 min thereafter for 1 h. Ratings of acceptability and sensory attributes (sweet, salty, chewy, moist, dense, fatty/oily/creamy) were also obtained. The area under the 75-min response curve (AUC) was used to quantify the overall satiety responses to each item. A satiety index (SI) was calculated by dividing the mean AUC for each food item by the mean AUC for a reference food. Significant differences were found in perceived satiety among the nineteen food items. The mean AUC was greatest for oatmeal, which was 4.78 times higher than the lowest AUC. A stepwise regression analysis was used to examine the relationship of individual food characteristics (macronutrient content, weight in grams, and volume), initial satiety level, sensory attributes, and liking to overall satiety. The obtained model revealed four variables that contributed significantly to perceived satiety: initial satiety, fat and protein content, and the perception of fatty/oily/creamy. Higher initial satiety (fullness) and higher fat content were associated with lower perceived satiety, while higher protein content and higher fatty/oily/creamy ratings were associated with greater satiety. A regression analysis to determine whether the sum of individual item satiety scores (AUCs), adjusted for serving size, could be used to predict the overall satiety of a meal resulted in a predictive equation with an R^2_{Adj} of 0.54. The intercept of the equation was close to zero and the slope (0.69) was interpreted as representing a correction factor for the diminishing growth of perceived satiety as a function of increasing kilocalories.

Overall, the data show that it is possible to index the perceived satiety value of individual ration components and meals, and that by developing a better understanding of the influence of the nutrient composition, physical, and sensory properties of a food on perceived satiety, it may be possible to develop or select ration components that produce lower levels of perceived satiety and which, in turn, may lead to increased consumption under field conditions.

1. Introduction

The US military has had a long history of conducting human research on the physiological, sensory, cognitive, and situational determinants of food intake. The purpose of these studies has been to gain a better understanding of the factors controlling soldiers' intake of rations in the field, in order to increase consumption of the rations and, thereby, optimize the nutrition and performance of the soldier. These research efforts take on added importance within the context of recent findings that soldiers operating in combat training exercises under- consume their rations, resulting in a 5–10% weight loss after several weeks in the field (Hirsch, 1995; Hirsch & Kramer, 1993; Meiselman, 1995; Meiselman, Hirsch, & Popper, 1988). Possible reasons for this loss of weight include the poor environmental and situational conditions in which the ration is typically eaten, negative attitudinal factors toward the food, poor hydration, reduced variety and acceptability, and the time and effort required to prepare and consume the ration.

In order to compensate for the reduced consumption of rations in the field, the US Army Natick Soldier Center has focused on two strategies. The first and more conventional strategy has been to optimize the sensory quality and acceptability of the rations. This strategy is based on the assumption that improved sensory quality

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will motivate greater consumption in the field. The second strategy, which is now being considered, is to design the rations to have higher caloric density while producing equal or lower perceived satiety, so that larger caloric quantities can be consumed before the soldier is fully sated. In order to achieve this latter goal, a better understanding is required of the differences in the perceived satiety of foods and of the physicochemical, sensory, and macronutrient-related factors that contribute to such perceptions.

In a recent series of studies using commercial food items, Holt and colleagues (Holt, Miller, Petoez, & Farmakalidis, 1995, 2001) developed a methodology to assess the perceived satiety value of foods using a "satiety index" (Holt et al., 1995). This index was derived from studies in which subjects were served isocaloric portions of different foods and their perceived satiety was tracked over the course of 2 h using a subjective rating scale. The area under the satiety response curve was calculated for each item and normalized to the obtained area under the curve for white bread. This produced a satiety index (SI) that was anchored to a value of 100 for white bread (SI values below 100 reflected foods that are less satiating than white bread, while those greater than 100 reflected foods that are more satiating).

Although the data from Holt's study on commercial foods is useful to the design of rations with tailored and/or optimized satiety, the validity, reliability and sensitivity of the method are directly related to the subjective measure of satiety that was used. Holt used a visual analogue scale (VAS) that was verbally anchored with seven verbal labels: "extremely hungry", "hungry", "semi-hungry", "no particular feeling", "semi-satisfied", "satisfied", and "extremely full". Such a scale constitutes a complex, hybrid scale that utilizes verbal labels that differ qualitatively, not simply quantitatively, along the measurement dimension. Also there is no evidence that the verbal labels define equal intervals along the measurement dimension, reducing the level of the obtained data to ordered metric data. Recently Merrill, Kramer, Cardello, and Schutz (2002) compared the Holt et al. (1995) scale to a variety of unidirectional and bidirectional VAS scales of "hunger", "fullness", and "amount could eat" for scaling the satiety of commercial foods used by Holt et al. (1995). Results showed that the "amount could eat" scale and the unipolar "fullness" scale were less reliable and less sensitive than the other scales tested. Although the Holt scale was not as sensitive as a simple bi-directional "hunger-fullness" VAS scale, its average reliability coefficient was the highest among the scales, a finding that is consistent with its numerous verbal labels that aid memory and reduce variability when placing a mark along the structured line.

In a recent program of research, our laboratory has developed labeled magnitude scales for a variety of hedonic dimensions, such as liking/disliking (Cardello & Schutz, in press; Schutz & Cardello, 2001) and comfort (Cardello, Winterhalter, & Schutz, 2003). In addition, we have recently developed a labeled magnitude scale for indexing perceived satiety (Cardello, Schutz, & Lesher, 2002, in press). This Satiety Labeled Intensity Magnitude (SLIM) scale improves the mathematical level of the obtained data, while better anchoring the ratings of different subjects to a common ruler (see discussions on labeled magnitude scales by Borg, 1982, Marks, Borg, & Westerlund, 1992, Green, Shaffer, & Gilmore, 1993, 1996 and Bartoshuk, 2000). In direct applications of the SLIM scale to the measurement of the satiety value of commercial and military foods, the SLIM scale was found to be a convenient, simple to use scale that enables greater discrimination of perceived satiety, especially at high degrees of hunger or fullness, while enabling ratio statements to be made about differences in the intensity of satiety sensations, e.g. "twice as hungry", "one-third as full", etc., both within and between subjects (Cardello et al., in press).

The aim of the present research was to combine previously established methodologies for measuring the perceived satiety value of foods (Holt et al., 1995; Merrill et al., 2002) with the newly developed SLIM scale in order to index the perceived satiety of a variety of military ration items. In addition we examined the relative contribution of the foods' nutrient composition, physical, and sensory properties to overall satiety, and carried out a predictive test of the ability to predict the perceived satiety of a meal from perceived satiety indices obtained for each food component comprising the meal.

It should be pointed out that, in this research, we treat satiety as a perceptual construct that results from biological mechanisms and psychological influences that are a direct consequence of the consumption of food. As a result, we use the terms "satiety" and "perceived satiety" interchangeably. Although a large body of literature exists on the description and measurement of "satiety" and "satiation," most of these papers treat satiety as a biological or behavioral construct, focusing on the sequence of the physiological processes of eating and meal termination (see Kissileff, 1982, 1984, 1985 for summaries and discussions of satiety as a construct). Although physiological processes are essential determinants of perceived satiety, the focus of our study was on the perceptual consequences of eating and on the ability to measure and predict these perceptual consequences and their relationships, both for meals and for the individual items that comprise them.

2. Method

2.1. Subjects

The study volunteers were military personnel and civilian employees of Natick Soldier Center, most of whom had participated in previous consumer acceptance tests. Subjects were not screened on any physical or demographic variable for inclusion in the study, because of a desire for external validity and the ability to generalize the data to the broad demographics of the military. In total, 88 subjects participated. This included 73 males and 15 females (a ratio of males to females that is generally representative of the military population). The ages of subjects ranged from 17 to 69 (mean = 41.0), height ranged from 1.5 to 2.0 m (mean = 1.8), and weight ranged from 56.7 to 111.1 kg (mean = 82.2). Ten to fourteen subjects tested each ration item. Some subjects volunteered to test more that one ration item but the majority of participants ($n = 60$) tested only 1–2 ration items. Only five subjects tested 3–5 ration items, while 24 subjects tested 6–9 items. However, these latter 24 subjects participated in a meal study (see below) that required them to test five ration items, both individually and together as a meal. All volunteers were told that the objective of the study was to evaluate people's perception of how hungry or full they feel prior to, during, and after eating a single food item or meal. As an incentive for participating, subjects were told they would receive a lunch meal of pizza following the test session. Subjects were allowed to bring reading material, work, or relax during the scheduled test session. Although, subjects were seated in separate booths, they were free to talk to one another, but were asked not to discuss the test food or any study related information.

2.2. Foods tested

In order to assess the perceived satiety value of military rations, it was important to test a variety of both existing and developmental ration items. The ration items chosen for testing included a combination of entrée, snack, and beverage items from the existing MRE (Meal-Ready-To-Eat) ration, as well as a several developmental items that are part of the future First Strike ration system. Another consideration in the selection of test items was to ensure the inclusion of foods that varied in flavor, texture, and/or viscosity. A few non-ration items were used for this purpose, e.g. oatmeal and yogurt, to ensure a wide range of perceived satiety for the items tested, as determined from previous studies (Holt et al., 1995; Merrill et al., 2002).

All preparation and serving procedures were standardized. The foods were measured into 300 kcal portions, with the exception of the pocket sandwiches, which were served at their usual serving sizes (bacon, 116 grams at 360 kcal and chicken, 120 g also at 360 kcal), because cutting them would compromise both their physical and macronutrient composition. To allow for valid comparisons between the two pocket sandwiches served at 360 kcal and all of the other items served at 300 kcal, AUC data for the pocket sandwiches were adjusted as follows: 300 kcal pocket sandwich AUC = 360 kcal pocket sandwich AUC*(5/6). Hot foods were prepared and served according to recommended serving instructions, and all foods were served on standard serving dishes with utensils and napkins. Table 1 lists the food items used, nutritional information, gram weight of the standardized portion size of 300 calories, and serving method. In addition, for purposes of assessing the contribution of the volume of the food to satiety, the volume of all tested items was calculated using a water displacement method in which a serving of the item was placed into a cylinder of water and the displaced water was used as a measure of its volume.

Table 1
The test foods, gram weight of standardized portion of 300 calories, nutritional information, and serving method

Test food	Test portion (g)	Pro. (g)	Carb (g)	Fat (g)	Serving method
Applesauce	384.0	0.0	75.0	0.0	3 packs placed in 2 bowls
Beverage, orange	897.6	0.0	73.9	0.0	2 1/2 packs poured in 2 cups
Beverage, grape	897.6	0.0	73.9	0.0	2 1/2 packs poured in 2 cups
Choc chip cookies	62.0	3.0	39.0	13.0	2 whole cookies
Choc sports bar	81.0	13.5	48.0	6.8	1 1/2 packages
Dairy bar—mocha	52.5	3.0	27.0	21.0	1 1/2 bars cut in 6 pieces
Hooah bar—choc	70.0	4.4	50.0	10.0	2 bars cut in 8 pieces
Hooah bar—PB	70.0	7.0	44.0	11.8	2 bars cut in 8 pieces
Oatmeal—maple	337.6	7.5	59.9	3.8	1 1/2 packs mixed in bowl
Power gel—apple	125.0	0.0	47.5	10.0	1 1/2 packs placed in bowl
Power gel—cranberry	125.0	0.0	47.5	10.0	1 1/2 packs placed in bowl
Pretzels	76.0	8.1	57.0	0.0	2 1/2 packs placed in bowl
Sandwich—bacon	116.0	21.0	47.0	10.0	1 sandwich cut in 2 pieces
Sandwich—chicken	120.0	16.0	47.0	12.0	1 sandwich cut in 2 pieces
Spaghetti	189.0	17.5	26.7	13.3	1 1/2 packs placed in bowl
Toaster pastry	78.0	3.0	54.0	7.5	1 1/2 packages
Toasted PB crackers	65.0	6.7	38.3	16.7	10 crackers
Turkey and potatoes	272.4	46.8	14.4	6.0	1 1/5 packages
Yogurt—strawberry	283.8	8.8	60.0	3.1	1 1/2 containers put in bowl

In addition to the individual food item testing, two complete meals were served as part of a predictive validity test of the obtained satiety indices. In order to ensure external validity, two conventional meals were chosen, as opposed to selecting "artificial meals" comprised of many items having low (or high) perceived satiety values. The latter approach would have required some meals (e.g. for low satiety items) to be comprised mainly of snack and pastry items. Both meals were comprised of an entrée, side dish, dessert, snack, and beverage, and all items were part of the Meal-Ready-to-Eat ration system. Each meal contained five food items equaling about 1000 calories (990 and 970 kcal), which is somewhat less than the average MRE ration meal (1250 kcal). Table 2 shows the breakdown of the macronutrient composition for each meal. The two meals differed from one another in that the first meal contained twice as much protein as the second meal while the other macronutrients were similar. The five food items served during this meal were not served at the 300 kcal portion used in the testing of individual items. Rather, for purposes of external validity, they were presented at their normal serving size as represented in an actual MRE meal e.g. 76.0 g of pretzels were served to the subjects in the individual food item test (300 kcal equivalent), but only 28.0 g were served in the meal test (normal portion size). Subjects who participated in these two meal tests had tested each of the individual food items that comprised the meal prior to participating in the meal test, enabling a within-subjects analysis of these data.

2.3. Procedure

The study period for assessing perceived satiety consisted of one weekday test session during the hours of 11:00 and 12:30. Subjects were instructed to eat their usual breakfast, however we requested that subjects not snack between breakfast and coming to the test session. At each test session, subjects were given one of the test foods. Each test session lasted approximately 90 min. During this time, participants were asked to eat the entire food item. Satiety measures were obtained before consumption, immediately after consumption, and every 15 min for 60 min. Ratings of acceptability and sensory attributes (sweet, salty, chewy, moist, dense, fatty/oily/creamy) were also obtained immediately after consumption. Each participant sat at a divided portion of a dining table, separated by blinding screens from other subjects. Subjects were asked to eat the ration item at a comfortable rate but to try to finish within the initial 10–15 min. During test sessions, subjects were not allowed to drink any beverages while they ate the test food. At the end of the hour, subjects were given ad libitum pizza with a bottle of spring water and told that they could eat as little or as much of the pizza as they liked for lunch.

2.4. Measures

Postprandial changes in feelings of hunger and fullness were assessed every 15 min using a Satiety Labeled Intensity Magnitude (SLIM) scale (Cardello et al., 2002, in press) and a 100-mm VAS. Both scales were used in order to assess the relative sensitivity of the two scales for indexing perceived satiety. The SLIM scale was originally developed on the basis of magnitude estimation studies in which subjects scaled the semantic meaning of a wide variety of English words and phrases used to describe the hunger and/or fullness produced by foods. These data were then used to construct the SLIM scale by placing specific words/phrases along a vertical line such that the relative location of the words/phrases along the line correspond to the relative mean magnitude estimates of their semantic meaning for indexing the intensity of hunger and/or fullness (Cardello et al., in press). The resulting SLIM scale is labeled vertically at the bottom with "greatest imaginable hunger" and at the top with "greatest imaginable fullness", "neither hungry nor full" appears at the middle of the scale and

Table 2
The foods comprising the test meals, gram weight of standard portion size and nutritional information

Test food	Portion (g)	kcal	Pro. (g)	Carb (g)	Fat (g)
Meal 1	746.2	970.0	54.0	135.0	24.5
Turkey and potatoes	227.0	250.0	39.0	12.0	5.0
Toasted PB crackers	39.0	190.0	4.0	23.0	10.0
Toaster pastry	52.0	200.0	2.0	36.0	5.0
Choc sports bar	54.0	200.0	9.0	32.0	4.5
Beverage, grape	374.2	130.0	0.0	32.0	0.0
Meal 2	819.2	990.0	27.0	149.0	29.0
Spaghetti	227.0	360.0	21.0	32.0	16.0
Applesauce	128.0	100.0	0.0	25.0	0.0
Pretzels	28.0	110.0	3.0	21.0	0.0
Choc chip cookies	62.0	290.0	3.0	39.0	13.0
Beverage, orange	374.2	130.0	0.0	32.0	0.0

the labels "slightly hungry (full)", moderately hungry (full)", "very hungry (full)", and "extremely hungry (full) are located along the scale at points corresponding to the magnitude of perceived satiety expressed by the label (see Fig. 1). The SLIM scale has been shown to be both more reliable and more sensitive to differences in perceived satiety than simple VAS (Cardello et al., in press).

It should be noted that the SLIM scale uses the anchor terms "greatest imaginable hunger (fullness)", which establishes a narrower judgmental range than does the use of the anchor "greatest imaginable sensation of any kind" as utilized by Bartoshuk (Bartoshuk, 2000; Bartoshuk et al., 2003) for comparing the intensity ratings of individuals known to differ in their experiences of taste sensations, e.g. supertasters. Although the *sensory experiences* associated with maximal fullness (or hunger) may be different for different sub-groups of the population, e.g. obese vs. non-obese, such sub-groups were not compared in the present study. Moreover, there is a lack of psychophysical evidence to demonstrate that conceptions of greatest *imaginable* fullness differ among individuals.

The VAS was a bipolar hunger/fullness scale labeled vertically with "Extremely Hungry" at the bottom and "Extremely Full" at the top. This scale is also shown in Fig. 1. To avoid carry over effects, a mix of VAS and labeled magnitude scales were used for other attributes. Ratings related to the food's sensory attributes, i.e. sweet, salty, chewy, moist, dense, and oily/fatty/creamy, were obtained using 100-mm intensity VASs (e.g. "Not at all Sweet" to "Extremely Sweet"). Acceptability ratings of the foods were obtained using a Labeled Affective Magnitude (LAM) scale (Schutz & Cardello, 2001; Cardello & Schutz, in press).

2.5. Data analysis

The perceived satiety response to each food was quantified as the area under the 75-min response curve (AUC). A satiety index (SI) score was then calculated by dividing the mean AUC for each food item by the mean AUC for a reference food. Although Holt et al. (1995) used white bread as a reference food, the choice of a reference food is arbitrary. Its main purpose is to serve as a convenient point of reference for product developers, menu planners and/or others, to enable them to compare the relative satiety value of different food items. Since the reference food will, by definition, have a satiety index value of 1.0 and all other foods will have a satiety index that is higher or lower, it is most useful to choose a reference food that falls close to the middle of the range of AUC values, so that roughly half the foods will have satiety indices above 1.0 and half will have satiety indices below 1.0. The chocolate Hooah bar, with a non-normalized AUC of 1053.95, was chosen as the reference food in this study because its satiety value fell in the mid-range of SI values and because of its wide popularity and use in military rations. The choice of a well known ration item as the reference food serves as an aid to ration developers and menu planners, who will be able to easily assess the relative influence on total meal satiety of adding or substituting one ration item for another in a particular ration meal menu.

A one-way ANOVA with Student Newman–Keuls post-hoc tests was conducted on the AUCs to assess differences in satiety indices among the nineteen food items. Since different subjects participated in the 19 tests, the data were analyzed for between-subject effects.

In order to examine the contribution of individual food item characteristics (macronutrient content, weight

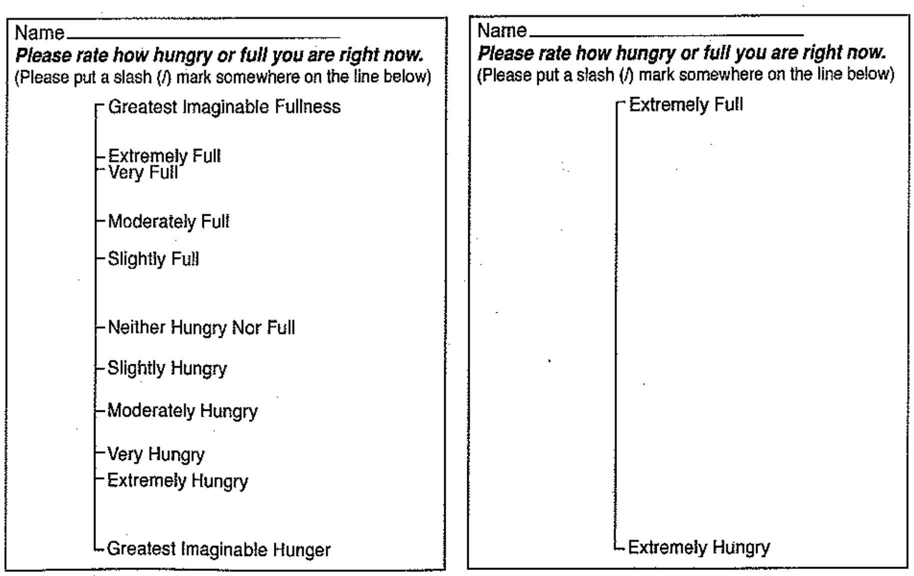

Fig. 1. Scales used to assess satiety ((left) SLIM scale and (right) VAS).

and volume), sensory attributes, baseline satiety ratings and liking to obtained satiety values, individual Pearson product-moment correlations and a stepwise multiple regression were conducted. Lastly, in order to assess the ability to predict the satiety produced by consumption of an entire meal from the satiety indices of the items comprising the meal, linear regressions were run between the sum of the AUCs for the individual items, adjusted for portion size, and the AUC produced by consuming those meals in their entirety. In addition to these two independent regressions, the data for both meals were combined, plotted, and an overall regression analysis performed. Due to three extreme outliers in the plotted data, a final regression model was developed using 17 of the 20 subjects.

3. Results

3.1. Perceived satiety ratings

In order to compare the perceived satiety responses obtained using the SLIM and VAS scales, a Pearson product–moment correlation was calculated between the perceived satiety ratings obtained on the two scales. Although there was a high degree of association between the VAS bipolar hunger/fullness ratings and the SLIM scale ratings ($r = 0.91$, $p \leqslant 0.001$), the ANOVA conducted to assess differences among the AUCs for the different food items showed the SLIM scale to be slightly more sensitive to differences between the AUCs for the foods, both in terms of overall F-values ($F = 2.70$, df = 18, 200, $p =< 0.001$ vs. $F = 1.83$, df = 18, 199, $p = 0.02$) and in terms of the number of significant differences among foods (8 food pairs vs. one food pair). This finding is consistent with prior research showing greater sensitivity of labeled magnitude scales over category or VAS (Schutz & Cardello, 2001; Cardello et al., 2002, 2003, in press). For this reason, as well as the advantage afforded by the ratio nature of the SLIM scale data, it was decided to use the SLIM scale data for subsequent data analyses and graphs.

3.2. Perceived satiety indices

Fig. 2 shows the mean Satiety Index (SI) for each ration item. Since the chocolate Hooah bar was the reference food item, it has an SI of 1.0. Items with a satiety index greater than 1.0 are *more* filling, while those with an SI less than 1.0 are *less* filling. For example, by looking at Fig. 2, we can see that oatmeal (SI = 1.96) is the most filling of the items. This finding is generally consistent with previous work by Holt et al. (1995) and by Merrill et al. (2002). Peanut butter crackers, on the other hand, were the least filling of the foods tested (SI = 0.41). Since the SLIM scale produces ratio level data, statements can be made to directly compare how filling one item is proportionally to another. Thus, it is valid to say that oatmeal is 4.78 times more filling than peanut butter crackers. Similarly, one can state that the chocolate sports bar (SI = 0.51) is only one-half as filling as the chocolate Hooah bar (SI = 1.0), etc.

The ANOVA conducted on the mean AUCs (and/or SIs) across the 19 ration/food items resulted in a significant effect of food type ($F = 2.70$, df = 18, 200, $p < 0.001$). Student–Newman–Keuls post-hoc tests revealed that the eight foods with the lowest AUCs (and

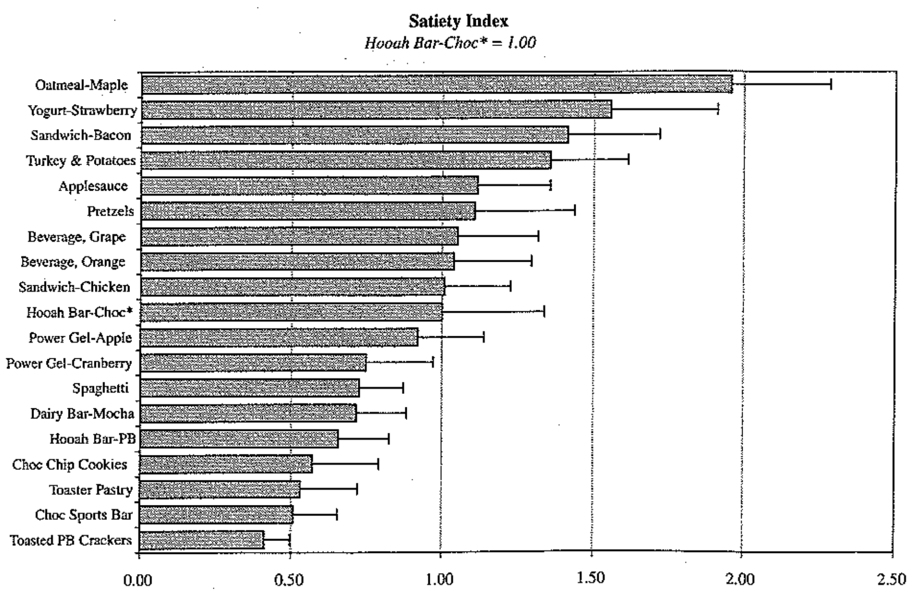

Fig. 2. Mean satiety indices and standard errors for the 19 ration/food items tested.

therefore, the lowest satiety indices in Fig. 2) were significantly less filling than oatmeal, but all other foods fell into the two overlapping subsets.

3.3. Relationship of macronutrient composition, physical, and sensory attributes to perceived satiety

Table 3 shows the individual Pearson product-moment correlations between each of the macronutrient, physical, and sensory variables and perceived satiety (AUC). Also included is the correlation between the initial perceived satiety rating (prior to consuming the test food) and the total perceived satiety (AUC) after eating the food. As can be seen, fat content and caloric density were significantly negatively correlated with satiety value, whereas the gram weight of the food was positively correlated with satiety. However, the highest and most significant association is the positive correlation between initial perceived satiety level (prior to consuming the test item) and the overall satiety value of the food. A stepwise multiple regression analysis was used to further explore the relationships among these variables. Table 4 shows the results of this analysis. The overall model was significant (R^2 Adjusted = 0.224; $p < 0.001$). Four variables were accepted into the model to predict satiety level. These were the initial satiety level (baseline SLIM rating), fat content in grams, the fatty/oily/creamy rating, and protein content in grams (Table 4). Higher initial SLIM ratings (i.e. greater initial fullness) and higher fat content were associated with *lower* total perceived satiety ratings while higher protein content and fatty/oily/creamy ratings were associated with higher ratings.

Table 3
Pearson product–moment correlation coefficients between each of the macronutrient, physical, sensory, and other test variables and satiety value (AUC)

Food attribute	Pearson correlation	Sig. (two-tailed)
Gram weight	0.153*	0.023
kcal per gram	−0.278**	0.000
Fat	−0.242**	0.000
Carbohydrate	0.089	0.187
Protein	0.129	0.057
Sweetness	−0.044	0.514
Saltiness	−0.107	0.113
Chewiness	−0.058	0.397
Moistness	0.062	0.361
Denseness	0.097	0.154
Fatty/oily/creamy	0.097	0.154
Liking (LAM scale)	0.057	0.404
Volume	0.121	0.075
Initial satiety (SLIM scale)	−0.347**	0.000

*Correlation significant @ $p < 0.05$.
** $p < 0.01$.

3.4. Prediction of perceived satiety values for meals from the perceived satiety indices of items comprising the meal

A linear regression analysis was utilized to assess whether individual item satiety scores (sum of the AUCs adjusted for portion size) predicted satiety of meals comprised of those items. Since the portion sizes of the five items utilized in each meal were the normal portion sizes for those items, rather than a fixed 300 kcal portion as used in the item assessments, individual item AUCs were adjusted to reflect the serving sizes of the individual items (e.g., if the normal portion size was 150 kcal, then the adjusted AUC was half of the obtained value for the AUC). For meal 1 (Table 2), the regression equation that was produced was $A = 0.695P + .889$, $R^2_{\text{Adj}} = 0.51$, where A = Actual satiety value of the meal and P = Predicted satiety value based on the sum of the adjusted AUCs of individual items. For the other meal, the regression equation was $A = 0.020P + 2082.182$, $R^2_{\text{Adj}} = 0.14$.

In order to assess the reason for the large discrepancy between the two predictive relationships, we plotted the regression data for the two meals separately. The poor regression model that was produced for the second meal appeared to be due to three outlying subjects in that meal. In order to assess whether these three subjects were outliers within the context of all subjects tested in both meal studies, the data for subjects participating in both meals were plotted together (Fig. 3). The subject points represented by the open circles and numbered 1–3 in Fig. 3 are clear outliers among the total of 20 subjects who participated in both tests. Removing their data from the combined data set and re-running the regression model produced a regression equation that was strikingly similar to the regression equation for the first meal data alone ($A = 0.688P - 6.978$, $R^2_{\text{Adj}} = 0.54$). As can also be seen in Fig. 3, the data for Subject 4 (4th

Table 4
The four significant variables and associated parameters of the stepwise multiple regression to predict satiety value from macronutrient, physical, sensory, and other test variables

Variable entered	B	Std. Error	t-value	Sig.
Initial satiety (SLIM scale)	−22.320	3.850	−5.797	0.000
Fat grams	−51.071	9.779	−5.222	0.000
Fatty/oily/creamy	−5.267	1.941	−2.714	0.007
Protein grams	−11.248	4.609	−2.441	0.015

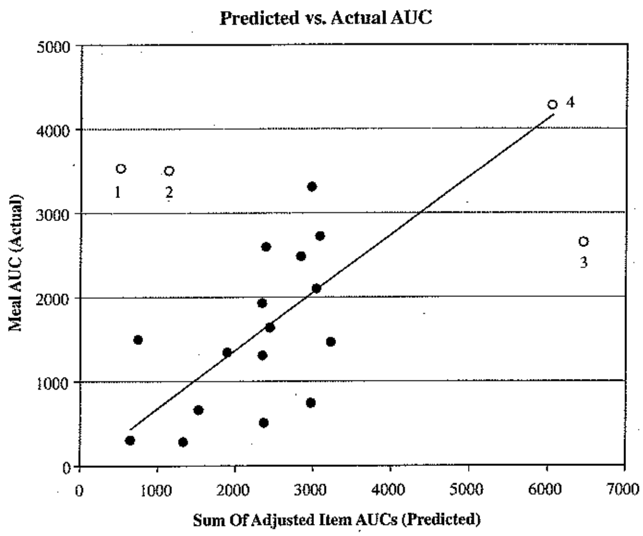

Fig. 3. Plot of the sum of the portion-size adjusted satiety indices for the foods comprising the test meal(s) (abscissa) and the actual satiety value (AUC) of the meal (ordinate). Open circles 1–4 reflect outliers in the data (see text).

open circle) might also be considered an outlier. However, we re-ran the regression without this one subject and found that both the slope and intercept of the regression line and the R^2 were virtually unchanged.

4. Discussion

The data from this study show that it is possible to index the perceived satiety value of military rations. In addition, the data suggest that there are a number of ration characteristics that differentially influence perceived satiety and that, potentially, these relationships can be used in future development efforts to engineer less satiating rations. The data in Fig. 2 show a wide range of perceived satiety values among the 19 tested food items. Peanut butter crackers, chocolate chip cookies, the peanut butter "Hooah" bar, and the mocha dairy bar had some of the lowest SI scores, yet these foods were among the highest in calorie per gram ratio. This inverse relationship between caloric density and satiety was confirmed by the significant negative correlation coefficient between these two variables, as seen in Table 3. The finding that foods that have higher energy density may be less filling than lower energy-density foods has been shown previously (Drewnowski, 1998) and is reflected also in the research conducted by Holt et al. (1995), who found that energy-dense cake, cookies, and chocolate were more palatable but less satiating than energy-dilute porridge, potatoes and fish.

Obviously related to the above association is the relationship of fat content to satiety. Many of the same foods with low SIs and high calorie per gram ratios in Fig. 2 also have high fat content (e.g. peanut butter crackers, chocolate chip cookies, mocha dairy bars). These foods also have lower perceived satiety indices than foods with lower fat content (e.g. oatmeal, yogurt, applesauce, pretzels, and fruit beverages). The correlation coefficients in Table 3 show a highly significant negative association of fat content with satiety.

Due to the large number of variables in this research and the inter-correlations among them (such as that between calories per gram and fat), it is perhaps more prudent to look at the results of the stepwise multiple regression that was conducted on the macronutrient, physical and sensory characteristics of the foods in order to predict perceived satiety (Table 4). Although the R^2 for the model was somewhat low, the analysis shows that four factors were the most significant contributors to the prediction model. These factors were the starting hunger/fullness value (prior to consuming the test item), fat content, the perception of fatty/oily/creamy, and protein content. Each was entered into the model in the order listed.

As seen in Table 4, fat content and the starting hunger/fullness value both had negative contributions to total perceived satiety, while protein content and the perception of fatty/oily/creamy had positive contributions. Thus, the findings that fat content has a negative contribution to perceived satiety while protein content has a positive association are, indeed, consistent with other recent studies that have shown that foods high in protein and carbohydrate produce greater satiety than do foods high in fat (Blundell & Burley, 1987; Blundell & MacDiarmid, 1997; Holt, Delargy, Lawton, & Blundell, 1999; Latner & Schwartz, 1999; Marmonier, Chapelot, & Louis-Sylvestre, 2000; Stubbs, Ferres, & Horgan, 2000). Interestingly, and in contrast to the negative relationship of fat content to satiety value, is the finding here of a positive association of the perception of fatty/oily/creamy to satiety value. This suggests an important and, perhaps, independent role for sensory vs. hedonic variables in satiety. While previous research has shown that the sensory quality and palatability of foods is correlated with intake and/or satiety (Drewnowski, 1998; Green, Burley, & Blundell, 1994), in general, these studies have shown that sweet and fatty foods result in greater intake/lower satiety. Although the positive hedonic component of these foods may well contribute to continued eating, i.e. reduced satiety, the present data suggest that the perception of foods as fatty/oily/creamy may serve to increase perceived satiety through a cognitive influence related to the belief that such foods are energy dense and, therefore, more filling. The influence of cognitions and other psychological "biases" on perception are well known in sensory science (see Dember, 1960; Gibson, 1966; Carderette & Friedman, 1974 and Meilgaard, Civille, & Carr, 1991) and the role of information, attitudes, and beliefs on the perception of the sensory and hedonic dimensions of food have also been demonstrated (Shepard, 1990; Cardello, 1994, 1998, 2003; Tuorila, Cardello, & Lesher, 1994a, 1994b, 1998; Kahkonen, Hakanpaa, & Tuorila, 1999; Kahkonen, Tuorila, & Rita, 1996; Westcombe & Wardle, 1997). These latter effects are often interpreted within the context of disconfirmed cognitive expectations (Anderson, 1973; Cardello, 1994, 1995, 2003; Deliza & MacFie, 1996; Olson & Dover, 1976; Schifferstein, Kole, & Mojet, 1999; Lange, Roousseau, & Issanchou, 1999), i.e., a change in perception that results from incongruence between cognitive expectations and sensory experience. The most common finding in this literature is that perceptions/attitudes assimilate the expectations (Sherif & Hovland, 1961). In the context of *perceived* satiety, a belief that a food is energy dense may increase perceptions of fullness through assimilation of the expectation that the food is more filling into the judgmental process. Such a cognitive effect may well explain other results in the satiety literature, e.g. Wooley's (1972) finding that drinks that appeared to be calorie dense produced greater satiety and reduced intake over those that did not.

The negative association of the starting hunger/fullness value with overall satiety is an interesting finding that warrants some discussion. This finding suggests that the more full an individual was just prior to eating the test item, the lower was his/her AUC for that food item. Such a finding can be explained in two ways. First, test sessions in this study were conducted at lunchtime. This time was chosen because most of the food items that were tested were not breakfast items. We did not want to test them in the morning, because the items would likely have lower acceptance at that time, and previous research has shown that foods that are less palatable are more satiating than foods that are more palatable (Drewnowski, 1998; Hill, Magson, & Blundell, 1984; Rogers & Schutz, 1992). Second, subjects were told that they could consume their normal breakfast that morning and that they would receive a full lunch meal of pizza after the test session. This was done to try to ensure that all subjects were as hungry as they normally would be just prior to eating lunch, because we wanted to determine satiety values for rations that would apply under normal field feeding circumstances. If subjects fasted overnight, they would be extremely hungry at the time of testing, and this might produce AUCs that were not representative of those that would be found at normal levels of hunger/fullness. Since the ultimate use for the data was to assist in the design of ration meals that would be consumed at normal mealtimes under normal levels of hunger/fullness, we chose to test the foods under normal mealtime hunger/fullness levels. However, given this testing strategy, it is possible that subjects had a wider range of initial hunger/fullness values than if they had all fasted overnight. Under these circumstances, the relatively small test portion of food (300 kcal) may have had less of an impact on perceived satiety over the next hour in subjects with higher initial fullness levels. Such a hypothesis is consistent with the well-known Weber Law (Weber, 1834) in psychophysics that maintains that difference thresholds for perceptual dimensions increase as a function of the starting intensity at which they are measured (Laming, 1986).

An alternative explanation for the importance of the starting hunger/fullness value is related to a possible "ceiling" effect in the judgment process. On any scale for rating satiety, whether it is a numerical category scale, a VAS, or the SLIM scale used here, there is an experimental artifact related to the starting point on the scale and the unstated experimental demands on the subject. That is, if a subject rates his/her starting fullness as being low, e.g. a 3 on a 10-pt category scale, then when his/her fullness increases after eating the test item, the subject still has a large set of *potential* ratings, i.e. 4–10, to assign to represent the new hunger/fullness level(s). This allows for a potentially large AUC. However, if the subject starts with a higher fullness rating, e.g. 7 on the scale, the *potential* size of the AUC is significantly reduced, because the ceiling on the possible judgments is still only a "10", regardless of the actual increase of hunger/fullness that the subject experiences. VASs can suffer from the same ceiling artifact, because the available distance to the top of the scale is smaller when a subject places a mark on the line to reflect a high fullness rating (assuming "extremely full" is at the top of the scale) than when he/she starts with a lower fullness rating. The SLIM scale used here, while having numerous mathematical and sensitivity advantages over category and simple VAS scales, may be still susceptible to this perceptual ceiling artifact if subjects fail to pay attention to the verbal labels on the scale, and instead, revert to the visual cue related to the length of line remaining in which to make judgments. From an analysis of the data, it is impossible to discern which of the above two factors may be operating in the present data.

Although not significant factors in the stepwise multiple regression, both the gram weight of the food and its volume had significant or near significant positive relationships with perceived satiety (Table 4). All of the foods used in this testing were standardized to a 300 kcal portion. Examination of Table 1 shows that the test portion by weight for applesauce (384.0 gm) is more than seven times greater than the test portion for the energy dense dairy bar (52.5 gm). The notion that the weight or volume of a food has an effect on satiety that is independent of calories has been documented in past research on satiety (Cooling & Blundell, 1998; Drewnowski, 1998; Rolls, Laster, & Summerfelt, 1989). The positive correlations of both gram weight and volume with satiety, as reflected in Table 3, lends support to the notion that weight and volume may be positively associated with perceived satiety. We must, of course, point out that there are only limited data showing a direct relationship between volume and satiety, e.g. Geliebter's (1988) work in which intake was measured following stomach distension using water-filled balloons. Furthermore, our use of a linear multiple regression model assumes the linearity of volume effects (as well as linearity among all other variables). Such a model may well oversimplify what is clearly a complex set of physiological and psychophysical processes.

Since the primary objective for developing a perceived satiety index for rations was to serve as an aid for designing ration meals with desired satiety values, it was essential that we test the ability of the individual satiety indices to predict total perceived satiety of a meal. By summing the AUCs for each food item comprising the two meals (on a portion-size adjusted basis) and regressing this summed value against the actual AUC obtained for the meal when eaten, it was possible to assess the predictive validity afforded by the perceived satiety indices. For one meal (Meal 1), the regression equation that was produced was quite good, although the equation for the other meal was less than satisfactory. By dropping three outlying subjects from the combined data, the satiety value of the meal for 17 of the 20 subjects could be predicted well from the sum of the satiety values for the individual meal components. Moreover, the parameters of the resulting regression equation are easily explained. That is, the constant (−6.978) of the equation is close to zero, relative to the values of the dependent variable being predicted, which ranged up to 4200. In addition, the slope of 0.688, while not equal to 1.0, can be interpreted as reflecting a multiplicative constant that is a function of the number of calories comprising the meal. In other words, since perceived satiety is assumed to be a negatively accelerated function of calories, if you were to take the satiety values for two items and add them together to predict their combined effect, you might well expect additively. However, as you add more items together, the total calories in the eaten meal increases relative to the number of calories used to predict the perceived satiety value of each meal component, so that the combined satiety values (each based on small total calories, i.e. 300 kcal) over-predicts the perceived satiety produced by consuming a larger number of them (i.e. five items = ∼1000 kcal). Related to this potential for overestimation in the summed values is the previously discussed psychophysical phenomenon by which larger sensitivity to differences occurs at low stimulus intensities than at high stimulus intensities. Thus, the slope of the regression equation (0.688) appears to be an expected multiplicative factor to take into account this overestimation.

With regard to our having dropped three subjects from the data to arrive at the above relationship between overall perceived meal satiety and individual item satiety indices, we should say that we did not drop these subjects lightly. However, the nomothetic imperative of science is to attempt to uncover the true relationship underlying a set of data, irrespective of idiosyncratic behavior and responses. In the present case, our data and the analyses of them indicated that 17 (85%) of the subjects responded in a consistent manner, while 3 (15%) responded in a quite inconsistent manner. Although we retrospectively searched for possible underlying correlates to link these 3 subjects and/or to differentiate them from the other 17, no obvious physical, demographic, experiential or other reasons could be identified to explain the inconsistencies in their data. The only common element that links them and that causes them to stand apart from other subjects is the lack of a meaningful relationship between their perceived satiety responses to the foods/meals. We could speculate that these individuals did not pay attention to the task during one or more of the test sessions, that they ignored the restrictions on eating prior to one or more of the test sessions, or that they used the rating scales incorrectly. However, regardless of the cause, their data were inconsistent from the point of view of predicting perceived meal satiety from individual item satiety indices. As such, our choice was either to keep them in the data set and to generally conclude that perceived satiety indices are poor predictors of total perceived meal satiety (which in some sense is a more perplexing conclusion) or else to eliminate them from the data set and to conclude that, for the vast majority (85%) of individuals in the population, it is possible to predict total perceived meal satiety from individual food item satiety indices. We elected the latter approach as being more consistent with the nomothetic imperative to search for unifying principles in the data, but remind the reader that the relationship shown in Fig. 3 is only representative of 85% of the test population.

The perceived satiety indices obtained from this study now form the basis for a much larger database on the satiety values of all military ration items. Once fully populated, this database will have the potential to be used to design ration meals that are tailored to produce a specific perceived satiety effect in soldiers. Given the current concern with the loss of weight of soldiers when deployed in field situations for periods as short as several weeks, the data obtained here may assist in the development of meals comprised of food items that have reduced perceived satiety for any specified number of kilocalories. It is predicted that such meals should have the effect of increasing the total caloric intake of soldiers and, thereby, help to offset the loss of weight that currently occurs. In addition, it may be possible to use the current data in conjunction with computer-aided ration menu tailoring systems, such as are currently being developed to optimize and tailor military meals to the specific metabolic needs of a given mission, while taking into account the macronutrient content of the meal, the acceptability of the meal components, and now, their perceived satiety values.

The current data showing the negative relationship between fat content and perceived satiety and positive relationship between protein content and perceived satiety can also be used as a potential aid in formulating and developing new ration components with desired hunger/fullness outcomes. Indeed, the data reported here support current efforts at Natick to increase the caloric density of rations through fat augmentation, since such caloric densification will not only increase total calories, but the increased fat content will have a negative effect on perceived satiety, thereby fostering further consumption. Although such augmentation is a desirable outcome for military applications, the negative impact of such a strategy for weight control in the public sector is obvious. Likewise the positive association of the sensory perception of fatty/oily/creamy in foods with perceived satiety suggests that ration designers should minimize the perception of fat-related attributes in high-fat rations, in order to maximize consumption of the items.

Lastly, the methodology developed here was designed to minimize the time and effort required to collect reliable satiety data in the face of doing so for hundreds of potential ration items. The methodology meets that goal and enables the future population of a large database on the perceived satiety values of all ration items. The fact that the predictive tests of meal satiety based on the sums of the satiety values of individual meal components were successful in the aggregate (3 of 20 subjects not withstanding) suggests that the developed methodology is effective for the purpose intended. In addition, the methodology can be readily adopted by commercial manufacturers of meals (e.g. frozen and or diet meals) in order to assist in the design of meal menus with specified perceived satiety outcomes.

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