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# The Threshold for Satiating Effectiveness of Psyllium in a Nutrient Base

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CYBULSKI, K. A., J. LACHAUSSÉE AND H. R. KISSILEFF. *The threshold for satiating effectiveness of psyllium in a nutrient base.* PHYSIOL BEHAV **51**(1) 89–93, 1992.—A combination of psyllium fiber with nutrients in a commercially available wafer (Fiberall—Ciba Consumer Pharmaceutical) was evaluated for its effectiveness in reducing food intake and appetite. Each of 15 nonobese healthy women received no wafers and four different amounts (39, 104, 169, and 234 kcal) of the fiber wafer with water, in a ratio of 13 kcal (and 0.565 g psyllium) wafer per 41.67 g water, 30 minutes prior to a test meal of macaroni and beef, on nonconsecutive days. Intake of the test meal and hunger ratings were both significantly reduced after intake of the two largest wafer amounts (169 and 234 kcal, respectively), in comparison with the two smaller amounts and none at all. The reduction produced by the largest amount compared to none at all was 122 kcal (about half the energy of the amount given). There were no significant differences in intake and hunger ratings among the two smaller amounts and none at all. Thus the threshold for intake reduction by this product with water lies between 104 and 169 kcal. Methodologically, this work underscores the importance of testing the satiating effects of foods at multiple levels before conclusions are drawn about their satiating effectiveness, and suggests that the threshold for significant reduction should be considered as a measure of the product's satiating effectiveness. The relative contributions of the nutrients, the fiber, and the water to the satiating effect still need to be determined.

Fiber   Human feeding   Satiating efficiency   Satiety   Hunger   Food intake   Preload

MEASUREMENT of the satiating effectiveness of foods offers both practical and theoretical challenges. The practical challenge is to find combinations of ingredients that will provide maximum satiety for minimum energy input, thereby enabling the consumer to reduce energy intake below expenditure and thus lose weight. The theoretical challenge is to understand the mechanisms by which food intake is controlled so the body can be "fooled into thinking its energy needs are satisfied," when they are not being met.

Previous studies from our laboratory suggested that such "fooling" may indeed be possible since soups were more effective than a combination of cheese, crackers, and apple juice, on a calorie for calorie basis, in reducing food intake in people (9). One possible theoretical explanation for the differential effectiveness of the two foods was that soups might expand the stomach and thereby increase access to postulated nutrient-sensitive sites in the stomach (3, 4, 12). However, it was also possible that the differential effects on satiety of soups and the combination were attributable either to different time courses in their satiating activities or different dose-effect curves of intake as a function of amount of food given before a main course, which we term "preload," to determine its effect on intake of the main course. Although we had assumed that the function relating test meal intake to preload size was linear, no evidence for this assumption existed. It was equally likely that the differential effects could be attributed to different thresholds in this dose-effect relation and that this relation was not linear.

The availability of a nutrient- and fiber-containing wafer, which, when consumed with water, might both expand the stomach and provide nutrients, gave us an opportunity to simultaneously test the hypothesis that the intake-preload function was smooth and linear for at least one preload, and that such a preload would be more satiating than previously tested preloads or at least as satiating as soup. If the intake-preload function were linear, the satiating efficiency (8) would provide the best comparative satiating measure. Satiating efficiency has been defined (8) as the negative of the slope of the line that relates intake of a test meal to the size of an administered preload. For the simplest case of only two preload levels, satiating efficiency is the ratio of the increase in preload size to the drop in test meal intake. If the line is curved or has discontinuities, the threshold for such effects would be a better index for comparing the satiating effectiveness of different foods than satiating efficiency. Naturally, the only way to determine the shape and slope of the intake-preload function is to examine intakes after several different amounts of preload.

## METHOD

### *Subjects and Subject Selection Procedure*

The subjects were 15 nonobese, nonsmoking, healthy women ranging in age from 18 to 25 years, recruited by means of

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newspaper advertisements and solicitation during college registration. In order to obtain this group, 28 subjects were screened, 19 were accepted, 2 were used as pilot subjects, 1 began to dislike the meal, and 1 dropped out. Subjects had to be within 15% of desirable weight for height (1). The subjects' demographic characteristics were (mean ± SD): age 19.87 years ± 1.36, weight 57.99 kg ± 4.52, height 169.43 cm ± 4.62, percent of desirable weight −2.21 ± 9.35, body mass index 20.23 kg/m$^2$ ± 1.86, and restraint score (7) 13.25 ± 6.58. They were not taking any medications (except for birth control pills) and had no allergies. Subjects were screened by means of a taste test and test meal procedure (see the Daily Procedure section) similar to a procedure that has been previously used in this laboratory (9). During the taste test, the subjects consumed small amounts of foods they would later be eating and rated them on a nine-point category scale of liking (14). In order to be accepted for the study, they had to rate the test meal at least 6, either during the taste test or after eating it as a meal (see the Daily Procedure section), and they had to eat at least 200 g of the test meal.

### *Daily Procedure*

The subjects came to the laboratory after an overnight fast and were given a standardized pretest meal (300 kcal) consisting of an English muffin with 1.5 pats of butter and 249 g (8 oz) of Red Cheek® natural apple juice. They returned to the laboratory 2.5 h after the start of the pretest meal and were given one of four different preload amounts or were not given a preload (see the Preloads section). The sequence of experimental conditions was counterbalanced by means of the same Latin-square for each group of five subjects. Thirty minutes after beginning the experimental condition, they were given a test meal which was placed on an eating monitor (10). The test meal consisted of four 11-oz packages of Stouffer's macaroni and beef with tomatoes (1.05 kcal/g) placed in a 2-qt bowl. Subjects were asked to fill out questionnaires (10,13) rating their feelings and bodily sensations at four different times (before the preload, immediately following the preload, immediately before the test meal, and 5 min after they finished the test meal). During the test meal, subjects were observed over a closed circuit video monitor, and they otherwise ate in isolation.

### *Preloads*

Four different amounts of the psyllium fiber wafers (Fiberall—Ciba Consumer Pharmaceutical, Raritan, NJ) with water or no preload were given as the experimental conditions. The amounts were evenly spaced 65 kcal apart, and the lowest amount was chosen at a level below what was expected to reduce intake, in order to determine whether the cognitive effects of merely consuming the preload would affect intake, as it apparently had in our earlier studies with soups (8). The interval between preload sizes was a convenient multiple of 6ths of wafer and slightly less than the interval (77 kcal) that had induced a significant effect in the previous study (8).

The following novel procedure of alternate eating and drinking was employed so that the wafers and water would be taken together in the same lengths of time for different preload sizes. The wafers were cut into sixths. Tape recordings were used to instruct the subjects exactly when to eat each wafer sixth and to drink from a small cup which contained 41.7 g of Deer Park water, after each sixth was eaten. There were separate tape recordings for each preload amount, and the time interval between eating episodes was inversely proportional to the number of wafer pieces consumed, thereby ensuring that consumption was evenly spaced through the 15-min interval and that the subjects always finished the required amount of preload within 15 min. During the preload, but not during the test meal, an observer was in the room to ensure that the subjects followed instructions.

The four preload amounts were 3, 8, 13, and 18 sixths wafer paired with 125, 333, 541.6 and 750 g water, respectively. In order to help eliminate cognitive cues about preload amount, the subjects were always presented with a plate of 30 wafer pieces and 18 cups of water, regardless of the amount to be consumed. Each sixth wafer contained 13 kcal and 0.65 g dietary fiber of which 87% was psyllium. The main energy containing ingredients in the wafer were corn syrup, flour, glycerin, sugar, molasses, oats, raisins, and vegetable shortening.

When the subjects were not given a preload, they were asked, via tape-recorded instructions, to write a composition, for 15 min, on what they were thinking about when they came for the screening test. This condition simulated the cognitive aspects of the eating situation without any preload being given. On the day the subjects were screened, they were presented with nine Ritz crackers, each with 1/3 slice Kraft muenster cheese and nine cups of 125 g of Deer Park water as the preload. The subjects were instructed to consume 3 Ritz crackers with muenster cheese and three cups (375 g) of Deer Park water (total of 117 kcal). The time interval between each eating episode in this trial was 7 min, 7 s, thereby ensuring that the preload consumption was evenly spaced throughout the 15-min interval.

### *Data Analysis*

The major dependent variables were intake of the test meal, duration of the test meal, liking of the test meal, and the linear and quadratic coefficients of the cumulative intake curve, fitted to a quadratic equation (11). Owing to technical problems, 8 of the 75 cumulative intake curves were not usable. One subject ate only 13 g in one meal, which was too small an amount to generate a curve. The major questionnaire variables were hunger, satiety, urge to eat, emptiness, and fullness ratings at the four time points. These variables were each analyzed by means of a one-way analysis of variance (ANOVA) with repeated measures (20), followed by planned comparisons for which least significant difference (LSD) tests were used. The dose-effect relation of preload to test meal was further analyzed by means of orthogonal contrasts which allowed testing for linear and quadratic components of the treatment sum of squares for significance (5). The GLM procedure of the SAS (17) statistical package for the PC (17) was used for all analyses.

In addition, a mixed-design (20) ANOVA was performed to determine whether the order of preload presentation had an effect on test meal intake. For this analysis, the between-group factor was the sequence of preload presentation, at five levels, one for each row of the Latin-square, and the within-subjects factor was amount of preload. Correlations between test meal intake and both postpreload and premeal hunger were performed at each preload level, among subjects, and regression analysis was performed on means of intake against means of premeal hunger, among treatments.

## RESULTS

### *Test Meal Intake*

There was a significant effect of the amount of preload on intake of the test meal, $F(4,56) = 6.04$, $p = 0.0004$. A LSD analysis revealed that the mean intakes after no preload (500 g, 525 kcal), 3 sixths wafer (475 g, 499 kcal), and 8 sixths wafer (475 g, 499 kcal) were not significantly different from one another, but they were significantly different from intakes after 13 sixths wafer (391 g, 411 kcal) and 18 sixths wafer (384 g, 403.12

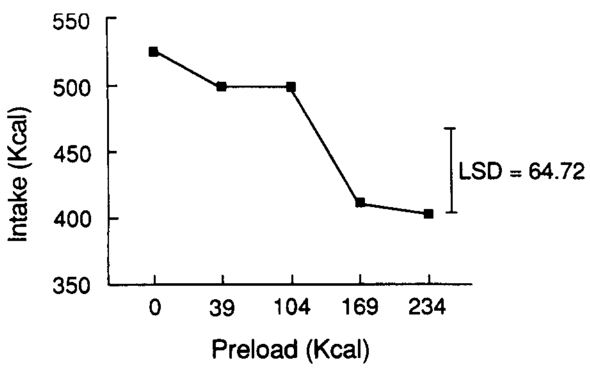


FIG. 1. Mean test meal intake for 15 subjects. The line labeled LSD is the least significant difference, within subjects, calculated by multiplying by 2 and dividing by 15 (n) the square root of the MS error and multiplying this whole expression by $t_{56}$ (*df* for the error term). Any difference between means on this figure larger than LSD is significant.

kcal). The amounts eaten after 13 sixths and 18 sixths wafer were not significantly different from one another. A preliminary analysis revealed no significant trial effect. The supplementary test on grouping of the sequences revealed no significant group by amount of preload interaction, $F(16,40)=0.60$, $p=0.8653$. Therefore, the sequence of preload presentation had no effect on intake of the test meal.

Intake of the test meal on the day the subjects were screened with the 117-kcal cracker and cheese preload was 492.13 g (517 kcal), which was close to the intake for the 8 sixths level of the wafer, which contained 104 kcal.

Although a test for departure from linearity in the dose-effect relation of intake to preload size was not significant, the shoulder in the relation (see Fig. 1) and the significant difference between only one of the three equally spaced 65-kcal intervals (104 to 169 vs. 39 to 104 and 169 to 243) suggests that a threshold exists between 104 and 169 kcal for intake reduction by the wafers.

### *Satiating Efficiency Computations*

Because the reduction in intake was not uniform across the different preload sizes, satiating efficiency could not be calculated precisely over the whole range of preloads. It is important to recognize how variable this measure can be under these circumstances and how misleading it might be to base such calculations on the assumption of linearity in the intake-preload function. When pairs of preloads were used as the basis for comparison of satiating efficiency across preload levels, satiating efficiencies varied from 1.35, when the two middle levels (8 sixths and 13 sixths) were compared, to 0.003 when the two smaller levels (3 sixths and 8 sixths) were compared. The average satiating efficiency when all levels were combined (negative of the slope of the intake-preload function) was 0.54.

### *Other Intake-Related Measures*

The other intake-related measures exhibited variable effects. Test meal durations were not significantly different among the preload amounts (range 6.05–6.97 min), nor were palatability ratings of the test meal (range 7.07–7.47), despite the fact that different amounts were eaten.

All but one of the cumulative curves fit the quadratic model with $r^2>.95$. The initial rate of eating (i.e., linear coefficient of the cumulative intake curve) did not differ, $F(4,47)=0.73$, ns, across preload amounts (range of means 81.5 for 18 sixths to 95.5 g/min for no preload), but the quadratic coefficient (half the rate of deceleration) was significantly, $F(4,47)=2.68$, $p=0.043$, smaller in absolute value after the largest preload (0.78 g/min$^2\pm$5.97 SD) than after no preload (−2.81 g/min$^2\pm$4.16 SD), 3 sixths (4.10 g/min$^2\pm$4.66 SD), and 13 sixths (−4.63 g/min$^2\pm$3.99 SD), but was not significantly different from 8 sixths (−2.38 g/min$^2\pm$2.97 SD). All but seven curves were significantly decelerated. The curves that did not show significant deceleration were distributed as follows across the preload conditions: Two occurred at 3, four at 8, and one at 13 sixths wafers.

### *Questions About Feelings and Sensations*

There were significant effects of the size of the preload on feelings of hunger, satiety, and the urge to eat immediately after the preload [hunger, $F(4,56)=8.78$, $p=0.0001$; satiety, $F(4,56)=3.95$, $p=0.0068$; urge to eat, $F(4,56)=5.74$, $p=0.0006$; see Fig. 2]. The pattern of results for these variables was basically the same as for intake. Subtle additional differences in patterns are shown in Fig. 2. The three lowest levels of preload (0, 3, and 8 sixths) resulted in significant differences on each variable from the two highest (13 and 18 sixths). Subjects reported feeling more hungry, less satiated, and having a greater urge to eat immediately following no preload, 3, and 8 sixths wafer than following 13 and 18 sixths wafer. These effects were still present 7 min later, at the time of the pretest meal questionnaire [hunger, $F(4,56)=11.68$, $p=0.0001$; satiety, $F(4,56)=4.78$, $p=0.0021$; urge to eat, $F(4,56)=6.51$, $p=0.0002$]. There were no differences in these variables across levels of preload either just before the preload or five minutes after the test meal.

In spite of the significant effects across preloads, there were no significant correlations, within any preload level, between test meal intake and hunger ratings taken either just after the preload or just before the test meal. However, there was a significant correlation between mean premeal hunger ratings and mean caloric intake [$r^2(3)=.97$, $p=0.0019$; slope = 2.26 kcal/mm; intercept = 306 kcal].

## DISCUSSION

These results suggest that psyllium fiber wafers taken with water are effective in reducing intake of a test meal. However, with an average satiating efficiency of only 0.54, simply adding any of the amounts of the wafers we used, together with water, to a meal would result in an increased, rather than a decreased, total (i.e., preload plus test meal) energy intake. However, it is still possible that the additional energy from the wafers might be less than the additional energy from some other courses, because the satiating effectiveness of most foods over their range of normal consumption is unknown.

The results of this study illustrate the variability in satiating efficiency when the intake-preload function is not uniform across preload sizes. The satiating efficiency of the wafers could be minuscule (0.003), between 3 sixths (39 kcal) and 8 sixths (104 kcal) wafer. In contrast, if the satiating efficiency is calculated between 8 sixths (104 kcal) and 13 sixths (169 kcal), the satiating efficiency becomes 1.35. Since the 3 (39 kcal) and 8 (104 kcal) sixths preloads are almost equivalent, calorically, to the two levels of soup and combination (i.e., cracker, cheese, and apple juice) preloads (37 and 115 kcal) that we have previously tested (9), it is important to note that, at these levels, the satiat-

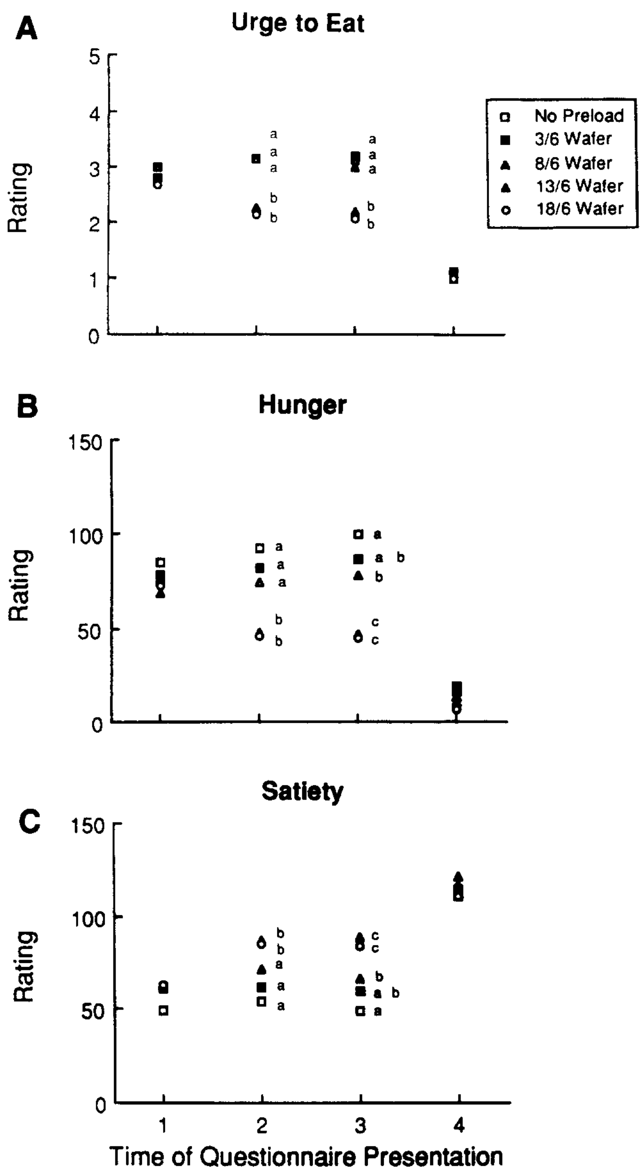


FIG. 2. (A) Means of questionnaire ratings for urge to eat on a 5-point category scale, (B) means of questionnaire ratings for hunger, on a 150-mm linear scale, (C) means of questionnaire ratings for satiety, on a 150-mm linear scale. Ratings are at the four times of questionnaire presentation: Time 1 (prepreload), Time 2 (postpreload), Time 3 (pretest meal), Time 4 (posttest meal). Means with the same letter are not significantly different from each other.

ing efficiency of the wafers is closer to that of the combination [0.02 in one experiment and 0.3 in another (9)] than to the soup (greater than 1.5). Even though satiating efficiency may vary for some foods across amounts given, the satiating efficiency ratio remains a viable way to compare the satiating effectiveness of different types of foods or food ingredients, provided both are tested at the same calorie levels.

If the satiating efficiency of the wafers is to be compared with that of other foods we have tested, two other points must be considered. First, the interval between preload and test meal was longer in the present study (30 min) than in the studies on soup (15 min) (9). Second, only two relatively low levels of soup were used. It is therefore not known what would happen to the intake preload function for soup if larger amounts of soup were given as preloads. What is needed to make direct comparisons of satiating efficiency is measurement of test meal intake after several equally spaced preloads. Because intake of the test meal is the only dependent variable when preloads are fixed, it is essential that each type of preload be equivalent in whatever dimension (i.e., energy, fiber, macronutrient, etc.) is being compared.

Even though it is not possible to make an exact comparison, a recent study (18), in which solid food units (SFUs) were used as a test meal and tuna fish sandwiches served as a preload, showed several similarities to the present results. These results suggest that a generalized mechanism controlling intake may be involved. Four different amounts of sandwich quarters were offered to human subjects as preloads along with a no-preload trial. The amounts were 148, 296, 444, and 592 kcal, respectively. The main significant difference was between the two middle preload sizes and amounted to 166 kcal. There were no significant differences between test meal intake following the 148-kcal load (approximately 421 kcal intake) and 296-kcal preloads (approximately 348 kcal intake), nor between the 444-kcal (182.4 kcal intake) and 592-kcal (106 kcal intake) preloads. In addition, subjects ate less after all preloads than after no preload at all (592 kcal).

One interpretation of these results is that there are two thresholds for effectiveness in reducing intake, one between 0 and 148 kcal and a second between 296 and 444 kcal. Since our maximum preload was below 296, we may have been able to see only the lower threshold, i.e., the one between 104 and 169. Whether the location of the lower threshold represents the operation of a general mechanism for intake reduction or is a coincidence because two solid preloads were used needs further exploration. However, it is likely that the result is general, since a significant reduction in intake occurred with a 115-kcal preload of tomato soup, which lies within the interval between 104 and 169 kcal, within which the threshold occurred in the present study. No reduction, and in fact a small increase in test meal intake, occurred with a 37-kcal preload, which is below the measured threshold in the present study.

On the other hand Rolls et al. (16) found that 66 kcal of tomato juice did not significantly reduce intake compared to no preload in women, but 88 kcal did reduce intake in men. It is therefore possible that liquid tomato products might be more satiating (i.e., have a lower threshold as well as greater satiating efficiency) than fiber wafers and water. Again, the critical test would be controlled studies of the two at the same energy levels.

It is also of interest to note that the threshold in the present studies appeared at a volume (between 333 and 542 g) consistent with previous results utilizing balloon inflation in which intakes were significantly reduced compared to no-preload conditions only when the balloon was filled with more than 400 ml of water (6). These results, therefore, underscore the need to determine the mechanisms by which the wafer-water combination results in suppression of intake.

Two positive results in the present studies should also be considered in the light of two earlier studies on fiber (2,15). In the former (15), nonobese men showed no intake reduction after high-fiber bread, though obese did. This result suggests that the wafers may be more satiating than high-fiber bread, and might be even more effective in obese than nonobese individuals. In the second study (2), the preload to test meal interval was probably too long (2.5 h), since Walike et al. (19) showed that preloading effects reached a maximum at 20 min and were less effective after 1 h. It is therefore impossible to compare the present results directly with preloads used by Burley et al. (2). The half-hour interval chosen for the present study was selected as a compromise between a very short interval in which the metabolic effects of the nutrients would not have had time to work and a longer one in which nutrients would have already been metabolized or stored. The role of the interval is certainly a factor that requires further study.

The present experiment suggests that more research is warranted to determine whether psyllium fiber, with or without nutrients, is effective in reducing food intake. Although there was a reduction in food intake in the present study, the decrease was not enough to compensate for the calories in the preload, and therefore, the total caloric intake was increased. Additional studies should be designed to test the hypothesis that the satiating efficiency of nutrients will be enhanced when the stomach is expanded by nonnutrients. What is most likely needed is a preload that will result in greater expansion of the stomach than has previously been used. Promise for the development of effective food products for food intake control may come from information on dose-effect curves of the satiating effects of various foods and food combinations, driven by knowledge of the general properties of foods that satiate and the mechanisms by which satiating effects are achieved.

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