Effect of Liquid and Solid Preloads on Eating Behavior of Obese and Normal Persons

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PLINER, P. L. Effect of liquid and solid preloads on eating behavior of obese and normal persons. PHYSIOL. BEHAV. 11(3) 285–290, 1973.—Although the obese are unresponsive to internal state and generally regulate their caloric intake poorly, recent studies suggest that the nature of the food may be important. An experiment was conducted to test the regulation of obese and normal weight humans after liquid or solid preloads of 200 or 600 calories. Normal subjects regulate in accordance with caloric preload on both the liquid and solid diets. Obese subjects regulate intake on the liquid diet and not on the solid diet.

Caloric regulation Obesity Eating behavior

SCHACHTER [14] has recently hypothesized that the factors controlling eating behavior differ markedly for obese and normal persons. The eating behavior of normal individuals is controlled by internal, physiological cues which vary with states of nutritional deficit and surfeit. The obese are relatively unresponsive to variations in internal state and eat chiefly in response to external, food-related cues. Experiments manipulating external cues have shown that the eating behavior of the obese is strongly affected by the taste of food [5,10], the sight of food [11,13] and the belief that it is mealtime [17]. These variables have little, if any, effect on normal subjects. In contrast, naturally occurring variations in internal cues have been shown to have little effect on obese subjects but large effects on normal subjects. Obese subjects are more likely than normals to undergo prolonged fasts voluntarily [4, 10, 17], and the subjective report of hunger in the obese (unlike normals) appears to be relatively independent of food deprivation [10] and gastric motility [21]. In addition, obese subjects are unresponsive to experimentally manipulated variations in internal state. Schachter, Goldman and Gordon [16] manipulated internal state in two ways: directly, by preloading some subjects with roast beef sandwiches and leaving the remaining subjects in a food-deprived state, and indirectly, by frightening some subjects and leaving the remaining subjects in a calm state (fear has been shown to decrease gastric motility and to increase blood sugar level which are two of the peripheral correlates of the ingestion of food). The subsequent food intake of normal subjects was strongly affected by both manipulations, but obese subjects ate no less when preloaded than when deprived and no less when frightened than when calm.

One additional study failed to find evidence of internal responsiveness for either obese or normal subjects. However, this study is not relevant for the present discussion because it is likely that demand characteristics overshadowed any evidence of internal responsiveness for either group of subjects [25]. The Schachter et al. [16] study thus provides the clearest evidence of the differences between obese and normal subjects in responsiveness to internal cues.

There are, however, two experiments using similar manipulations of internal state which appear to contradict the results of the Schachter et al. study. Nisbett [12] preloaded underweight, normal, and obese subjects with twenty-five ounces of Nutrament, containing 750 calories, or twenty-five ounces of Diet Pepsi, containing two calories. Two hours later he presented subjects with a test meal. Consistent with expectation, normal and underweight subjects responded strongly to the caloric manipulation, eating less following the Nutrament preload than following the Diet Pepsi preload; but contrary to expectation, obese subjects also responded strongly to the caloric manipulation. In a similar study, Nisbett preloaded subjects with twenty-five ounces of Nutrament or a noncaloric pill and presented a test meal five minutes later. Again obese subjects as well as normal and underweight subjects responded to the caloric manipulation.

While there were many procedural differences between the Schachter et al. study and the Nisbett studies, perhaps the most obvious was that the preloads in the former were solid foods and in the latter, liquid foods. It is possible that obese individuals are unresponsive to internal cues only when these cues arise from solid foods and are as responsive as normals to cues arising from liquid foods. Although it is not immediately obvious why a solid–liquid distinction should be important, it is clear that solid and liquid foods
differ on many dimensions, one or more of which could have physiological effects which interact with obesity.

The present study was designed to test this notion of differential responsiveness to solid and liquid foods for the obese. The amount of food eaten by obese and normal subjects was measured at a test meal following ingestion of four different preloads: high calorie solid, low calorie solid, high calorie liquid, and low calorie liquid. The predictions are straightforward. If the hypothesis is correct that the obese are differentially responsive to solids and liquids, the caloric manipulation should affect the eating behavior of obese subjects given liquid preloads, while the eating behavior of obese subjects given solid preloads should remain unaffected. Normal subjects should, of course, respond to both caloric manipulations.

**METHOD**

Subjects

Subjects in the experiment were 48 obese and 48 normal undergraduate males attending Columbia University. A subject was considered to be of normal weight if his actual weight was no more than 10% over the ideal weight for his height, based on the Metropolitan Life Insurance Tables [8]. If has actual weight was 15% or more over the ideal weight for his height, a subject was considered to be obese. In assigning subjects to weight groups, weight deviations were rounded off to the nearest whole percentage. A more detailed account of the selection criteria can be found in Schachter et al. [16]. Table I shows the characteristics of subjects in each weight group.

Procedure

Subjects were recruited for an experiment, the ostensible purpose of which was the measure the effect of a vitamin on ability to concentrate. At the time of recruitment, subjects were asked not to eat on the day of their experimental appointments and as a reward for fasting were promised lunch at the end of the experiment. Upon his arrival at the laboratory, each subject was told that he would be given a capsule containing either the vitamin or a placebo and would then be asked to perform a concentration task. The necessity for fasting was explained as a means of ensuring that subjects did not consume any of the vitamin in its natural form with the food they ate.

Subjects were scheduled for one of three times of day: noon, 1:45, or 3:30 p.m. Four subjects in each condition were run at each of the three time periods. Since preliminary analyses showed no effect of the time variable, data for the three time periods were combined. Whenever possible, two subjects were scheduled for each experimental session. The pairs of subjects received the experimental instructions in the same room, were placed in different rooms to work on the concentration task, and remained separated until the end of the experiment. Sixty-eight of the 96 subjects were run in pairs and the remaining 28 subjects were run singly. Since examination of the data revealed no systematic effect of this slight difference in procedure, the two groups of subjects were pooled for all analyses.

**Preloads**

After hearing the introductory spiel and before taking the capsule, each subject was asked to ingest one of the four preloads under the pretext that it was necessary to ensure proper absorption of the vitamin.

*Liquid preloads.* The 600 calorie preload consisted of 400 cc of a formula prepared with a skim milk base to which was added butter, sodium caseinate, dextrose, and water. The 200 calorie preload consisted of 400 cc of a one-third dilution of the above formula, thickened with carrageenan, a noncaloric substance. The liquid preloads were served at a temperature of approximately 8°C. Both preloads were flavored with a noncaloric strawberry flavoring and were served in tall glasses resembling those used in soda fountains. The two preloads were virtually identical in appearance.

*Solid preloads.* The 600 calorie preload consisted of a medium-sized piece of white cake, sliced into layers filled with strawberry jelly and covered with white icing. The 200 calorie preload consisted of a medium-sized piece of angel food cake, sliced into layers filled with dietetic strawberry jelly and covered with white icing. The cakes were served on paper plates and subjects were provided with dessert forks. The two preloads were virtually identical in appearance.

*Caloric composition of preloads.* Nutritionally, the solid and liquid preloads differed from one another in one obvious respect. The compositional breakdown of the liquid preloads was approximately 45% carbohydrate, 15% protein, and 40% fat. For the solid preloads the breakdown was approximately 84% carbohydrate, 6% protein, and 10% fat. While it would have been desirable to use solid and liquid preloads with identical caloric compositions, preliminary work proved this to be unfeasible.

**TABLE 1**

SUBJECT CHARACTERISTICS

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean Height (inches)</th>
<th>Mean Weight (pounds)</th>
<th>Mean Age (years)</th>
<th>Mean % Overweight</th>
<th>Range of % Overweight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>48</td>
<td>70.1</td>
<td>156.6</td>
<td>19.9</td>
<td>+ 1.2</td>
<td>- 5.6 to + 9.3</td>
</tr>
<tr>
<td>Obese</td>
<td>48</td>
<td>71.0</td>
<td>202.2</td>
<td>19.9</td>
<td>+27.3</td>
<td>+14.7 to +63.7</td>
</tr>
</tbody>
</table>
Test Meal

Following ingestion of the preload, each subject was given a capsule allegedly containing either the vitamin or the inert substance, but in fact containing a placebo in every case. Scheduled next was the concentration task, intended merely to be consistent with the rationale of the experiment and to allow a one-hour interval between ingestion of the preload and presentation of the test meal. Following the one-hour interval, each subject was presented with the test meal and told, "Here is the lunch I promised you – it’s chicken and roast beef sandwiches. Have all you want because I have lots more. I’ll be back in a little while."

Subjects were given 12 min in which to eat the test meal, which consisted of three roast beef sandwiches and three chicken sandwiches cut in quarters. Each quarter-sandwich contained about 60 calories, divided roughly equally between bread and meat filling. Subjects were also given a cup of water with the meal.

Preload Ratings

Within the solid and liquid conditions, an attempt was made to equate the 200 and 600 calorie preloads for taste, appearance, and texture in order that subjects would have identical cognitions concerning the caloric value of the preloads. To measure the success of this attempt, each subject was asked immediately after the test meal to rate his preload on 7-point scales on two dimensions – richness and heaviness. Informal pretests indicated that high ratings on these two dimensions connoted high calorie content while low ratings connoted low calorie content. The data showed that subjects did rate the 600 calorie preloads as richer and heavier than the 200 calorie preloads; however, there were no significant interaction effects involving weight, and correlations between ratings of the preloads and number of sandwiches eaten at the test meal were low and nonsignificant. Therefore, it seems unlikely that subjects’ cognitions about the caloric value of the preloads influenced the outcome of the experiment.

RESULTS

To review the expected results briefly: if the hypothesis that the obese are differentially responsive to liquids and solids is correct, they should be affected by the caloric manipulation when given liquid preloads and unaffected when given solid preloads. Normal subjects should, of course, respond to both caloric manipulations. Specifically, it was predicted that both obese and normal subjects would eat less following the 600 calorie liquid preload than following the 200 calorie liquid preload, and that normal subjects would eat less following the 600 calorie solid preload than following the 200 calorie solid preload. Obese subjects in the solid conditions were expected to eat the same amount regardless of the caloric content of the preload.

Eating Data

Table 2 shows the mean number of sandwich quarters eaten by subjects in each condition. The analysis of variance showed a significant main effect of calories (F (1,88) = 24.06, p<0.01). This is hardly surprising since in every pair of conditions subjects given the 200 calorie preloads ate more than their counterparts given the 600 calorie preloads. However, this effect was accounted for largely by the behavior of normal subjects. When the weight group were analyzed separately, there was no significant main effect of calories for the obese group.

The interaction between weight and calories was also significant (F (1,88) = 6.45, p<0.05), replicating Schacter's earlier findings that the obese are generally less sensitive to internal cues than are normal subjects. The caloric manipulation had a much greater effect on normal subjects than on obese subjects. Normal subjects given the low calorie preloads ate 7.98 sandwich quarters while normal subjects given the high calorie preload ate only 4.51 sandwich quarters. Obese subjects in the low calorie conditions ate 7.68 sandwich quarters while obese subjects in the high calorie conditions ate almost as much – 6.58 sandwich quarters.

<table>
<thead>
<tr>
<th>TABLE 2</th>
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<tbody>
<tr>
<td>MEAN QUARTERS OF SANDWICHES EATEN*</td>
</tr>
<tr>
<td>Normal</td>
</tr>
<tr>
<td>Solid</td>
</tr>
<tr>
<td>200 Calories</td>
</tr>
<tr>
<td>600 Calories</td>
</tr>
<tr>
<td>Average of 200 and 600 calories</td>
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</table>

*The standard deviation for each of the eight conditions is given in parentheses.
The analysis of variance effect most relevant to the differential sensitivity hypothesis is the second-order interaction (weight x state x calories). This interaction is not significant, suggesting that the obese may not, in fact, be differentially sensitive to solid and liquid foods. However, closer examination of the means in Table 2 suggests that abandoning the differential sensitivity hypothesis would be premature. Normal subjects given a 200 calorie solid preload ate 3.25 quarter-sandwiches more than normal subjects given a 600 calorie preload, while obese subjects showed a trivial corresponding difference of only 0.12 quarter-sandwiches. Comparison of the relevant means for subjects given the liquid preloads yields a difference of 3.69 quarter-sandwiches for normals and an appreciable difference of 2.08 quarter-sandwiches for the obese. Planned comparisons between the pairs of means are presented in Table 3. As expected, both comparisons were significant for normal subjects, who ate less following 600 calorie preloads than following 200 calorie preloads in both the solid and liquid conditions. Obese subjects failed to respond to the caloric manipulation in the solid conditions. In strong contrast, however, obese subjects in the liquid conditions ate significantly fewer quarter-sandwiches following the 600 calorie preload than following the 200 calorie preload.

For the purpose of demonstrating differential sensitivity it would, of course, have been more comforting to find a significant second-order interaction in the analysis of variance; however, in light of the fact that only one of many possible interactions was of interest, the failure to find a significant second-order interaction is not surprising. But the combination of an $F$ of 4.97 in the obese liquid group, and the reassuringly low $F$ of 0.02 in the obese solid group strongly suggests that the obese are indeed differentially responsive to internal cues arising from solid and liquid foods.

One can look at the data in a still more precise manner by testing only the one interaction which is of interest. The differential responsiveness hypothesis predicts that the difference in amounts eaten following the 200 and 600 calorie preloads should be smaller for subjects in the obese solid group than for subjects in the obese liquid, normal solid, and normal liquid groups; a linear comparison of means shows that this prediction is strongly confirmed ($F = 7.18$, $p<0.01$). Thus, a precise test of the one interaction which is relevant to the differential responsiveness hypothesis is highly significant. This comparison is not, of course, statistically independent of the planned comparisons presented in Table 3. It should, therefore, be considered an alternative to rather than a supplement to the analysis in Table 3.

To summarize, the differential responsiveness prediction was confirmed. Obese subjects adjusted their caloric intake following liquid preloads and failed to adjust their caloric intake following solid preloads; normal subjects adjusted their caloric intake with both solid and liquid preloads. In addition, the obese were found to be less sensitive overall to internal cues than normals, a replication of earlier findings.

### DISCUSSION

The present experiment replicated within one study the results of Schachter, Goldman and Gordon [16] who found that obese subjects unlike normals were unresponsive to internal cues following solid preloads and those of Nisbett [12] who found that obese subjects did respond to internal cues following liquid preloads. Thus, at the level of empirical generalization there seems little doubt that obese human subjects respond differentially to the internal cues consequent to liquid and solid preloads. But, of course, the question remains: why are the obese responsive to internal cues in the case of liquids, yet unresponsive with solids, while normals are responsive to both types of preload? There would appear to be at least two plausible explanations for this difference. First of all, it is possible that the cues signalling nutritional status provided by ingestion of liquid foods are different from those provided by ingestion of solid foods, and the obese differ qualitatively from normals, being responsive to the first set of cues yet unresponsive to the second. On the other hand, it is possible that liquids and solids provide the same physiological cues but that the cues provided by liquids are stronger or more easily discernible than those provided by solids, and obese subjects differ only quantitatively from normals, being generally less responsive to internal cues and failing to adjust their intake only when the cues are not easily discernible.

The data contain a hint that the latter possibility may be true. Examination of the sandwich data for normal subjects shows that the difference between the number of sandwich quarters eaten in the high and low calorie solid conditions was 3.25 while the corresponding difference in the liquid conditions was 3.69. This difference of differences is not statistically significant, but it does show a slight tendency on the part of normals to respond more strongly to the liquid manipulation than to the solid manipulation.
and suggests that liquids may indeed provide cues as to nutritional status which are more easily discernible than those presented by solids. If this is the case, then the difference between obese and normal subjects may well be quantitative rather than qualitative. However, since the evidence is so tenuous, it may be best to consider this question unresolved.

While the fact that in three of the four pairs of experimental conditions subjects given 200 calorie preloads ate significantly more than subjects given 600 calorie preloads indicates that subjects were responding to physiological cues, it should be noted that caloric regulation was not perfect, even for normal subjects. If one computes the total number of calories consumed by subjects in the course of the experiment by summing preload calories and sandwich calories, it is apparent that subjects in the low calorie preload conditions ingested fewer calories in total than those in the high calorie preload conditions. Thus, either subjects in the 200 calorie conditions underate or subjects in the 600 calorie conditions overate to some degree. Stellar has reported similar results [20]. It is, of course, possible that, while there was not perfect regulation within the experiment itself, subjects may have compensated for the discrepancy in a later meal or meals.

It is interesting to note that the results of the present study resemble the findings of researchers working with another obese organism— the hypothalamic hyperphagic rat. Several important aspects of the eating behavior of rats made obese by bilateral lesions of the ventromedial hypothalamus show strong similarities to the eating behavior of obese humans [15]. With regard to external cues, obese rats, like their human counterparts appear to be extremely responsive to the taste qualities of their food [22]. There is also evidence indicating that, like obese humans, these rats are unresponsive to internal cues arising from deprivation and satiation [9]. However, with hypothalamic hyperphagic rats as well as with obese humans, there are exceptions to this finding of internal unresponsiveness — and examination of these exceptions reveals that they occur when animals are tested with liquid diets [19,24].

While procedural differences between most of the animal studies and the present study make drawing an exact parallel impossible, evidence of differential responsiveness from two independent areas of research lends some convergent validity to the notion that a distinction between liquids and solids is a potentially fruitful one. Of course, an important question still remains: what difference between liquid and solid foods can account for such findings? To pinpoint a specific physiological mechanism is clearly beyond the scope of this paper; however, an examination of general differences between solid and liquid foods can perhaps provide a clue as to the locus of the mediating process. Before such general differences are discussed it may be recalled that in the present experiment the solids and liquids also differed in a specific way — compositionally. The solids contained a higher proportion of carbohydrates and a lower proportion of proteins and fats than did the liquids. However, it seems unlikely that the compositional difference rather than a more general solid-liquid difference can account for the results. The Schachter et al. [16] study which also demonstrated a lack of responsiveness of the part of obese subjects to a caloric manipulation used solid preloads with compositions similar to those of the liquid preloads used in the present experiment. It is, therefore, unlikely that the failure of obese subjects in the present study to respond to the caloric manipulation was a function of the caloric composition of the solid preloads.

More generally, holding constant caloric content and composition, liquid foods (a) are of greater weight than solid foods; (b) contain greater absolute amounts of water than solid foods; (c) leave the stomach at a faster rate than solid foods; (d) are of greater volume than solid foods; (e) are of lesser caloric density than solid foods; and, (f) differ texturally from solid foods.

Each of these factors could have a possible mediating effect on one or more of the physiological mechanisms which have been implicated in the regulatory process. For example, Mayer [7] has suggested that the availability of glucose as measured by arterio-venous differences in blood glucose is the important factor in short term regulation. Since it is not until food has left the stomach that the greatest part of absorption takes place, making carbohydrates available to the tissues, it is possible that solid-liquid differences in gastric emptying time could be important mediators of the availability of carbohydrates. Janowitz [6] and Berkun, Kessen, and Miller [1] have shown that oropharyngeal factors are of some importance in the regulatory process. Obviously, liquid and solid foods, differing texturally, would present greatly differing stimuli to the oropharyngeal receptors. Gastric factors have been proposed by many investigators as important hunger signals. Gastric factors have also been shown to be important on the opposite end of the regulatory continuum; that is, in the cessation of eating. Janowitz [6] and Smith and Duffy [18] maintain that gastric distension is an important factor in the stopping of eating. Characteristics of liquid and solid foods which might differentially affect these gastric cues are emptying time and volume. In addition, Thomas and Baldwin [23] have recently reported the presence in the lower gastrointestinal tract of receptors which are sensitive to pressure. If such receptors also exist in the stomach, the weight of food in the stomach could also mediate afferent signals from these pressure receptors. Still another regulatory mechanism has been suggested by Smith and Duffy [18]. They hypothesize that water balance and the concentration of body fluids might be involved in the normal mechanisms of hunger. Possibly, differences between solids and liquids in absolute water content and caloric density could have effects in mediating water balance.

It is clearly impossible to isolate the crucial solid-liquid difference which can account for the present results in the presence of the existing theoretical confusion in the area of regulation of food intake. However, it is possible that the present study can suggest a means for reducing this confusion. By systematically manipulating each of the dimensions on which solids and liquids differ, while holding the others constant, and looking at the subsequent success or failure of subjects to adjust their intake, it should be possible to isolate the crucial difference between solid and liquid foods. One could then look more carefully at the physiological process which would be likely to be mediated by this variable. For example, if volume appeared to be the important variable affecting subjects' ability to adjust their intake, one could look more closely at gastric factors as likely physiological regulators. Such a program of research could eventually solve the riddle of the regulatory process.
REFERENCES