Eating Behavior: Lessons From the Real World of Humans

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Food intake by normal humans has been investigated both in the laboratory and under free-living conditions in the natural environment. For measurement of real-world intake, the diet-diary technique is imperfect and tends to underestimate actual intakes but it appears to be sensitive, can detect subtle influences on eating behavior, and produces reliable and valid measures. Research studies in the real world show the multivariate richness of the natural environment, which allows investigation of the complexities of intake regulation, and even causation can be investigated. Real-world research can overcome some of the weaknesses of laboratory studies, where constraints on eating are often removed or missing, facilitatory influences on eating are often controlled or eliminated, the importance of variables can be overestimated, and important influences can be missed because of the short durations of the studies. Real-world studies have shown a wide array of physiologic, psychological, and social variables that can have potent and immediate effects on intake. Compensatory mechanisms, including some that operate with a 2- to 3-d delay, adjust for prior excesses. Heredity affects all aspect of food-intake regulation, from the determination of body size to the subtleties of the individual preferences and social proclivities and the extent to which environmental factors affect the individual. Hence, real-world research teaches valuable lessons, and much more is needed to complement laboratory studies. Nutrition 2000;16:800–813. ©Elsevier Science Inc. 2000

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INTRODUCTION

Even though eating behavior has been intensively studied over the past century, an understanding of how it is regulated has been elusive. The research has not yielded practical results, and as a result science has failed to produce effective therapeutic interventions for over- and under-weight. In fact, the problem of overweight and obesity, rather than being resolved, has increased dramatically.1 It is the thesis of this presentation that part of the problem resides with the focus on laboratory research. Some of the strategies employed in laboratory research produce results that are valid for the laboratory but miss essential variables that differ between the laboratory and the real world. This results in an overestimation of the importance of some variables, the underestimation of the importance of others, and missing altogether other salient influences.

The differences between laboratory and naturalistic research are primarily due to differences in the degree of control over sources of variance. The high degree of control that occurs in the laboratory is both its virtue and its curse. The control allows the researcher to isolate independent and dependent variables such that causal connections can be readily discerned. However, the researcher has to know ahead of time which variables are important to investigate and which need to be eliminated or controlled. In a situation where the important contributors to the behavior may be unknown, the researcher may well eliminate or control very salient variables and thereby miss some important contributors to the behavior. Also, the fact of control can create an artificial situation that humans can respond to in ways that do not reflect their typical behavior. In addition, because laboratory studies eliminate most sources of variance other than the independent variable, the proportion of the variance accounted for by this variable can appear artificially large.

In the real world most behaviors are affected by multiple causal factors. This multivariate environment allows for compensations, modulation, and interactions between variables that are difficult to detect in the laboratory. A variable that may significantly alter behavior in the laboratory may have little or no effect in the real world due to a compensatory reaction or a modulating influence of another variable. These compensatory or modulating variables may well be eliminated or controlled in the laboratory and thus the importance of the independent variable may be grossly overestimated. For example, a modulating variable that is present in the real world is the cost of food. This can markedly reduce the influence of otherwise salient variables such as palatability or even hunger. Also, as will be reviewed later, intake may be affected by a short-term variable on the day that it is studied in the laboratory. The participant’s intake may be markedly increased or decreased by a potent environmental variable and no immediate compensation is apparent. However, a compensatory reaction occurs 2 to 3 d later.2 This is missed in the laboratory because 2- to 3-d periods are normally not investigated.

Of course, the lack of control in natural-environment studies presents a separate set of challenges. The lack of control makes the identification of causal factors difficult and the large numbers of variables that are present and simultaneously influencing the behavior makes it difficult to discern the influence of subtle factors. However, the development of modern multivariate techniques has markedly relieved this problem. In fact, although variables are not physically controlled, their influence can be mathematically controlled and their influence extracted from the variance in the...
MEASURING FOOD INTAKE IN THE REAL WORLD

The Diet-Diary Method

There are many methods used to estimate the nutrient intakes of humans (for review, see Thompson and Byers). However, these methods are designed to measure overall usual-intake levels and do little or nothing to measure actual eating behavior. This limits the ability to identify the factors that affect intake. I and my colleagues have been developing and using the 7-d diet-diary method to measure the detailed eating behavior by humans in their natural environment and have included measures of contextual and psychological variables. The participants are asked to record for 7 consecutive d, in a pocket-sized diary, their eating behavior, feelings, and the environmental context. The 7-d period has been found to be an acceptable duration for maintaining the subjects’ motivation and tolerance of diary recording and still produce regular, stable, and interpretable data. This procedure has good reliability, with reasonable agreement between records repeated after as much as 2 y.

Even though the diet-diary method is a self-report, it has been found to have a high degree of validity when tested empirically. Gersovitz et al. had elderly subjects keep a 7-d diet diary. Unknown to the participants, the experimenters surreptitiously measured the actual amount of food consumed at lunch. They found good agreement between the diary records and the actual amounts eaten. Also, Krantzler et al. using a similar technique with college students found 87% agreement between 7-d records and surreptitious measures of intake. The 13% disagreement usually involved non-reporting of small items, especially condiments.

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To help ensure that reliable and valid records will be kept, we offer a contingent reinforcer; a detailed nutritional-composition analysis of the reported diets. The subjects usually express great interest in this report and have participated willingly with this analysis as the only incentive for participation. The participants are informed that record keeping often produces a change in the photographs to aid in the coding. The inclusion of the photographs increased the estimates of the amounts of the macronutrients ingested in the meals by 6% to 9%. Hence, this procedure would appear to help overcome a potential problem with underreporting. In addition, it is possible that the fact of taking the pictures increases the accuracy of the written records because the subjects know that the pictures will be seen with their entries.

Underreporting and Reactivity

Even though the diet-diary procedure appears to be reliable and valid, there is considerable evidence that reported intakes are about 20% below what should be ingested by weight-stable subjects of comparable activity levels. Diet-diary records produce estimates of energy intakes that are 18% to 23% below the levels that have been empirically determined to be required to maintain body weight. The doubly labeled water technique provides an accurate measure of energy expenditure. In some studies, good correspondence has been found between these estimates and those produced by diary self-report methods. However, a number of studies have suggested a serious, approximately 20%, difference between measured expenditures and the intake estimates produced by self-reports.

To assess the degree to which the intakes reported in our diet diaries were representative of the participants’ typical daily intakes, reported intakes were compared with the estimated basal metabolic rate (BMR) for each participant. Basal metabolic rate was estimated from the participant’s weight by considering age and sex according to the procedure outlined by Schofield et al. The ratio of the reported daily food-energy intake (EI) to the BMR was calculated for each participant (EI/BMR). A reasonable cutoff for identifying underreporting is EI/BMR < 1.1. This includes participants whose intake is at least 10% above their BMR. For the entire sample, the mean EI/BMR was 1.28 (0.013). This mean was about 18% below the expected level of 1.55 for typical intake and was commensurate with the estimates of diet-diary reported-intake differences from expenditure estimated with the doubly labeled water technique.

Almost exactly two-thirds of the participants who were above the cutoff (67.9%). These results suggest that the intake estimates that were obtained with the diet-diary technique are on the order of 18% below the level that would be expected for the participants to be maintaining their body weights.

These low levels may or may not present an interpretive problem, depending on the nature of the questions being addressed in the research. When the absolute amounts of nutrients ingested are required, these levels can be a problem. However, in most research applications, the quantities ingested by one group or condition are compared with those ingested by another group or condition. Although subjects may differ in the degree to which they tend to report low intake, these individual differences would be expected to be distributed randomly among groups. Hence, the error created by low estimation would be expected to affect different groups approximately to the same extent and thus would not systematically change relative values. Hence, the errors should not produce confounding probabilities but rather increase type I error probabilities. Indeed, the relative differences between males and females remain the same even with the low estimation of absolute intakes, as would also appear to be true for the differences between obese and lean subjects. The literature does suggest that caution must be exercised when comparing adolescents or obese subjects with other groups because the estimation may be lower in these groups. Hence, the technique is not recommended for measurement of absolute intakes among groups but appears to produce reliable, valid, and reasonably accurate intake records when applied to nonobese adult subjects.

These studies suggest that, regardless of the veracity of the reporting in the diaries, diary recording can produce reports of
intake levels that are not representative of the individual’s typical daily intake. This may be due to underreporting of ingested nutrients, reactivity to the measurement procedure, or a combination of both. Underreporting involves an inaccurate report of actual intake. Conversely, reactivity involves an unintentional or intentional decrease in intake during the recording period. Goris and Westerterp\textsuperscript{22} presented evidence that reactivity-producing undereating is responsible for low-intake estimates in lean women but that a mix of underreporting of fat intake and undereating is responsible in obese men.\textsuperscript{28} It is not possible within the current data set to ascertain whether the low-intake reports were due to underreporting or to reactivity-induced undereating.

To investigate the extent to which the diet-diary meal intake results might have been biased by the inclusion of participants who reported unrealistically low intakes, an analysis was performed comparing the intakes from participants who were above and below the estimated basal metabolic rate (BMR). The participants who reported intakes that were above the cutoff had average meal sizes that were 6.6\% larger than those who reported intake below the cutoff value. However, the relation between meal size and other significant variables such as palatability and social facilitation did not differ between groups.

The correlations between six different variables that are known to affect meal size and the size of the meals ingested were calculated for both the low- and acceptable-reporting groups (Fig. 1). These correlations were calculated separately for each subject and then averaged across groups. The correlation between the number of people present and the meal size, reflecting social facilitation,\textsuperscript{29-31} was positive and significant and did not differ between groups. The correlation between self-reported hunger and the meal size, reflecting motivational state,\textsuperscript{33,34} was positive and significant. The low reporters’ correlations were slightly but significantly smaller than those of the acceptable reporters. The correlation between self-rated palatability and meal size, reflecting hedonic responsiveness,\textsuperscript{35,36} was positive and significant and did not differ between groups. The correlation between the estimated content of the stomach at the beginning of the meal and the meal size, reflecting responsiveness to prior energy intake,\textsuperscript{14,37} was negative and significant and also did not differ between groups.

The evidence presented and reviewed indicates that the diet-diary method produces reliable and valid results and that the errors that tend to occur are not a problem in most research applications. It is clear from the current analysis that the relations between significant variables that affect eating do not appear to be changed by low reporting. The correlation data demonstrate that the relations between significant variables that affect eating are not changed by low reporting, suggesting that this measurement problem does not affect the nature of the conclusions that can be reached about the factors that affect eating.

Nevertheless, caution must be exercised with regard to interpreting the absolute levels of nutrients reported because these tend to underestimate customary intakes due to undereating and/or underreporting. In addition, there are potential problems when using the technique to compare certain groups, in particular obese and adolescent subjects, because these groups tend to produce estimates that underestimate customary intake to a greater extent than typical comparison groups.\textsuperscript{17,18,21} The technique is only useful if the subjects are highly motivated and competent. This requirement restricts the usefulness of the technique for investigating the intake of uncooperative groups. We were able to apply the technique to investigating the meal patterns of head-injured subjects by having the caregivers maintain the records, but this was laborious and it was difficult to motivate the caregivers to accurately maintain the records.\textsuperscript{38}

**INTAKE IN THE REAL WORLD VERSUS THE LABORATORY**

With the diet-diary technique, we have been able to assess intake regulation in free-living normal humans in their natural environments. By comparing what has been learned with this technique with the results of laboratory studies, it has become apparent that, in comparison with real-world research, there are a number of significant shortcomings with laboratory research. In particular, real-world constraints on eating are often removed or missing in the laboratory, real-world facilitatory influences on eating are often controlled or eliminated in the laboratory, the importance of variables can be overestimated in the laboratory, and important influences can be missed because of the short durations of laboratory studies. In addition, real-world studies can be used to ascertain causation, and the multivariate richness of the real world is an asset in the study of intake regulation. Each of these issues is discussed in the following sections.

**Real-World Constraints on Eating Are Often Removed or Missing in the Laboratory**

There are circumstances in the real world that constrain the amount of intake at a meal and the timing of meals that are often absent in the laboratory setting. A major factor that profoundly influences real-world intake is the cost of food. In animals it has been demonstrated that the “cost" of intake can have a profound effect on the intake pattern.\textsuperscript{39} This constraint is most often missing in the laboratory environment. This “free” feeding can lead to marked overconsumption in laboratory research. For example, with the diet-diary technique we find that a typical lunch meal averages 2.4 MJ.\textsuperscript{40} Adjusting for an underestimation of 20\% yields 2.9 MJ. Yet in laboratory studies where subjects are allowed free access to foods, intakes are sometimes seen at over double the levels that we observe, from 6.1 to 6.9 MJ,\textsuperscript{41} 4.6 to 6.4 MJ,\textsuperscript{42} 6.7 to 7.3 MJ,\textsuperscript{43} or 4.3 to 5.3 MJ.\textsuperscript{44} For snacks, we typically find, using the diet-diary technique, that an average snack is about 1.7 MJ.\textsuperscript{40} In contrast, in
It is interesting that this relation between prior interval and meal size for humans was observed for North Americans. In French culture, dining is a much more important event, and work and socializing are often scheduled around eating rather than the reverse, which is the predominant case in North American culture. In a sense, eating is less constrained by outside schedules in France than in North America. This cultural difference is reflected in a difference in the meal pattern. The meal intake of free-living French subjects under ad libitum conditions shows a significant relationship between the meal size and the following interval.53

In total, these results suggest that regulation is flexible and can occur by adjustments to either meal size or frequency, depending on the environmental and social contexts. Because the environmental and social contexts are frequently eliminated or held constant in the laboratory, the influence of these very important variables on intake are rarely observed or recognized.39

### Real-World Facilitatory Influences on Eating Are Often Controlled or Eliminated in the Laboratory

Studies of intake by humans in the laboratory are usually scheduled around the convenience of the experimenter and the participants. As such, intake is usually studied during the daytime and much research occurs around lunch time. Unfortunately, this strategy may miss important diurnal or circadian influences on intake. Studies using the diet-diary technique have demonstrated that there are substantial and important changes in ingestive behavior that occur over the course of the day. Intake is usually studied during the daytime and is often scheduled around the convenience of the experimenter and the participants. As such, intake is usually studied during the daytime and much research occurs around lunch time. Unfortunately, this strategy may miss important diurnal or circadian influences on intake. Studies using the diet-diary technique have demonstrated that there are substantial and important changes in ingestive behavior that occur over the course of the day. Such a pattern can also be discerned in rats in the laboratory.55,56 These results suggest that the satiating effects of food changes with the time of day. If one is worried about the overigestion of food, then noontime is not a good choice as the time for testing because at noon the satiating effects of food remain rather high. It is only in the late evening that the participant becomes much less satisfied by intake and may be more vulnerable to overeating. This important influence can be entirely missed in laboratory research, where time of day is held constant. It should be noted that these effects are culturally dependent. The pattern of results described appears to be true for North Americans and the Dutch. However, the French

### Pre and Post-Prandial Correlations

![Pre and Post-Prandial Correlations](image)

FIG. 2. Schematic diagram of the intermeal intervals and the meal sizes that were used to calculate the pre- and postprandial correlations.

In the real world there are constraints not only on the amount of food ingested in a meal but also on the timing of meals. This produces subtly different patterns of intake in the laboratory than seen in the real world. The so-called postprandial relationship is a case in point. Many years ago it was discovered that rats eating “ad libitum” in the laboratory delay their next meal by an amount that is proportional to the amount of food eaten in the preceding meal (Fig. 2). This was shown by a significant correlation between the size of the meal and the following interval until the next meal.46–48 In contrast, the duration of the interval before the meal is not related to the size of the meal ingested. This relation between meal size and after-meal interval has also been observed in humans eating under ad libitum conditions in the laboratory.49 This led to the conclusion that regulation occurs by adjusting the time between meals, meal frequency, and not meal size. However, it is clear that in the real world humans adjust intake primarily by adjusting the amount eaten in the meals and not the timing or frequency of eating.50 In addition, in the natural, normal, human environment, the meal size is found to be predicted by the prior interval and the relation between meal size and after-meal interval is non-significant.13,14 In other words, for humans in the real world, meal size is adjusted based on the period of time since the previous meal, but how long they will wait till the next meal is not affected by how much they have just eaten. This is the complete opposite pattern to that observed in the laboratory (Fig. 2).

The key difference between the laboratory and the real world that is probably responsible for the observed difference in the patterns of intake is that in the natural, normal, human environment, the timing of meals is constrained by external schedules dictated by work and social commitments. The human is frequently not free to adjust eating time. Thus, regulation occurs by adjusting how much is eaten, which suggests that the laboratory findings of a relation between meal size and after-meal interval should be observed only under completely ad libitum conditions of testing and, conversely, should not be observed when the timing of eating is constrained. We tested this notion in the laboratory by constraining rats to eat only at particular times of the day. When these constraints were imposed, the real-world humanlike pattern was evident, such that the interval before the meal significantly predicted the meal size, whereas the relation between meal size and after-meal interval was not significant.51–52

![Diurnal Meal Pattern](image)

FIG. 3. The mean meal sizes (left), interval until the following meal (middle), and the satiety ratio (right) observed during the morning, afternoon, and evening periods.
show a slightly different pattern in that noontime meals tend to be the same size as evening meals.\textsuperscript{53}

In the laboratory, humans are normally studied on weekdays. However, using the diet-diary technique to study real-world intake has shown that humans eat differently on the weekends than during the week (Fig. 4). In general, 8% more is ingested on weekends than on weekdays.\textsuperscript{57} It is doubtful that this represents anything other than environmental and cultural effects,\textsuperscript{58} and it is doubtful that different effects would be observed in the laboratory if participants were studied on the weekends. However, an 8% change in intake is rather substantial and not observed in laboratory studies. If the goal is to understand overeating, then studying the factors that alter intake on the weekend may be a fruitful approach to identifying factors promoting the overingestion of nutrients.

Another major influence on intake that is controlled or removed in laboratory research is the participants’ expectancies. The individual’s beliefs about the foods presented can have a marked influence on intake. Shide and Rolls\textsuperscript{59} labeled yogurt preloads that did not differ in fat content as either low fat or high fat. The participants who believed that the yogurt was low fat ate more at a subsequent meal than those who believed it was high fat. In the real world, such expectancies are manipulated by package labeling and advertising and may be a major influence on eating. Caputo and Matte\textsuperscript{60} investigated this manipulation by supplying free-living participants with a daily lunch for 6-d periods and instructed them that it was normal, low fat, or high fat. In fact, the lunches did not differ in fat content. However, the participants ate significantly more during the rest of the day when they thought it was low fat than when they were led to believe that it was high in fat. In most laboratory research projects, expectancies are controlled; in the real world, they are not. These expectancies about the foods that people ingest may have a more potent effect on intake than the variable studied and manipulated in the laboratory and may override the effects of these variables in the real world.

A very significant facilitatory influence on intake that is usually controlled or eliminated in the laboratory is the effect of the presence of other people. Normally, in laboratory research with both humans and non-humans species, the individual is isolated and behavior is studied. In the real world, using the diet-diary method, it has been demonstrated that this procedure eliminates a very potent influence on intake, i.e., social facilitation. To investigate social effects on intake, we simply looked at the amounts ingested in meals eaten alone versus those eaten with other people present. It was found that the meals eaten with other people present were on the average 44% larger than meals eaten alone,\textsuperscript{31} including larger amounts of carbohydrate, fat, protein, and alcohol.

This social effect appears to occur as a result of an increase in the duration of meals rather than an increase in the rate of intake at the meal.\textsuperscript{61–62} Also, who the individual eats with influences the amount ingested in the meal.\textsuperscript{63} Females eat significantly more (13%) when eating with a male than when eating with another female, whereas males eat the same amount regardless of the sex of their companion. Meals ingested with spouse, family, or friend are significantly larger (22%, 23%, and 14%, respectively) than meals ingested with others but without family or friends present, whereas meals ingested with coworkers are significantly smaller (16%).

In addition, it was shown that social facilitation is an orderly phenomenon that can be measured with the correlation between the number of people present and the amount eaten in the meal. This social correlation has been found to be significant and positive under many conditions and with many different groups. Social facilitation can also be described as a functional relation between meal size and the number of people present (Fig. 4). Meals eaten with one other person present were 33% larger than meals eaten alone, whereas 47%, 58%, 69%, 70%, 72%, and 96% increases were associated with two, three, four, five, six, and seven or more people present, respectively. These data can be fit nicely by a power function,\textsuperscript{30} which is characteristic of the social-facilitation phenomena in general.\textsuperscript{64}

Much has been learned about this phenomenon, but it has been learned primarily with observational studies. Subsequent to these real-world observations, social facilitation was verified in the laboratory.\textsuperscript{65} However, controlling and eliminating social effects in the laboratory by isolating the participant for study disallows this very salient influence on intake from being observed or documented. Only when the constraints on variables, such as the social context, time of day, and subject expectancies are removed, such as occurs in the real world, can the true characteristics of these salient influences on intake be revealed.

Causation Can Be Established in Real-World Studies

A purported shortcoming of real-world research is that causation cannot be established. It is true that it is more difficult to establish causation in real-world studies, but it can be done. To demonstrate causation, three prerequisites must be met: correlation, time precedence, and nonspuriousness. Obviously, in the case of the number of people present, the first prerequisite, correlation, is satisfied. Because the people eating with the subject are there from the beginning of the meal, the time precedence prerequisite is also satisfied. The final criterion, nonspuriousness, is more difficult to deal with in the real world. With the lack of control over variables, it is difficult to demonstrate that a third factor may not be responsible for the observed covariation.

Spurious relationships can be investigated in real-world contexts. For example, the relation between the presence of other people and meal size may result from a covariation produced by a third factor. In particular, the time of day, alcohol intake, snacks, locations such as restaurants, or weekends are possible covariates. People could simply be eating more on occasions and in circumstances where more people tend to be present. To investigate these potential artifactual explanations, meals were identified that occurred under specific conditions. It was demonstrated that, although the covariances existed, they did not account for the social correlation. Strong, positive, and significant correlations between meal size and the number of other people present, social correlations, were found separately for meals eaten during the breakfast period, the lunch period, or the dinner period, eaten in restaurants, at home, or elsewhere, eaten accompanied by alcohol intake or without alcohol, for only snacks or only meals,\textsuperscript{40} or for meals eaten during weekdays or during weekends.\textsuperscript{58}
Even with this evidence, because of the observational nature of the research, it is not acceptable to conclude that the presence of other people is the cause of the increased intake. To establish causation, the number of other people present was actively manipulated by instructing subjects to eat alone by themselves for a 5-d period, eat normally for another 5-d period, and eat only with other people for a third 5-d period. The order of these periods was randomized. In comparison with the normal instruction period, the subjects ingested on average 212 kcal, or 11%, less per day when instructed to eat alone.66 This result suggests that the presence of other people is indeed the cause of the increase in intake at meals. Subsequent laboratory studies have supported the idea of a causal connection between the presence of other people and increased meal size. Clendennen et al.65 demonstrated that, when subjects were required to eat a test meal with one or three other subjects, they ate significantly more than when alone.

It should be noted that the magnitude of the effect of eating alone, 11%, is considerably smaller than the magnitude of the social-facilitation effects observed in unmanipulated contexts, as reported above. In fact, the meal sizes reported during the manipulated-alone condition were 20% larger than the alone meals during the normal condition,66 which may indicate that separating naturally occurring meals that just happen to be eaten alone from those that happen to be eaten with others may overestimate the impact of social facilitation of eating. Alternatively, it may suggest that the subjects compensate by increasing meal size in the alone condition to bring overall intake to more nearly normal levels.

Another example of the investigation of causal connections in real-world research involves the effect of alcohol ingestion on overall food-energy intake. Alcohol is an important contributor to human energy intake that is frequently ignored in laboratory research. Alcohol intake in the real world appears to supplement rather than displace food energy in the diet.67 Using the diet-diary technique to look at normal humans who did not ingest alcohol versus moderate alcohol drinkers showed that the total food-energy intakes of drinkers and nondrinkers are not substantially different for carbohydrate, fat, or protein. However, drinkers ingested more total food energy because of the alcohol intake. In addition, drinkers ingest comparable amounts of carbohydrate, fat, or protein on days that they drink and on days that they do not drink alcohol. However, on drinking days, more total food energy is ingested because of the additional energy from alcohol.

These observations about alcohol intake could be due to a causal connection between alcohol intake and total energy ingestion. However, this cannot be determined by the strictly observational studies. To investigate causation, Orozco and de Castro68 simply required moderately alcohol-consuming participants to refrain from alcohol intake for a 5-d period. During the 5-d period of normal alcohol intake, the participants ingested comparable amounts of carbohydrate, fat, or protein as they did during the 5-d abstinence period. However, due to the added alcohol food energy, the participants ingested 9.2 MJ versus 7.6 MJ during the abstinence period.

These studies demonstrate that causation can be investigated in real-world contexts. They demonstrate that the presence of other people is a causal factor that increases the amount ingested at meals. They also show that alcohol intake is a causal factor that increases overall food-energy intake over the course of the day. Hence, not only can observations be made in the real world to uncover important variables in the control of intake, but causation can be established by manipulating these variables.

The Importance of Variables Can Be Overestimated in the Laboratory

One of the most frequent criticisms of the results of real-world research projects is that the variables studied only account for a very small proportion of the variance in intake. In general, it is true that only small proportions of the variance can be accounted for by the independent variable. However, this is actually a strength of the method because the importance of the variable to actual intake is demonstrated, whereas in the laboratory, large proportions of the variance can be accounted for, but in such an artificial manner that the real importance of the variable can be misrepresented. In laboratory studies, most if not all of the sources of variation in the dependent variable are controlled or eliminated. As a result, because there are so few other influences producing variance, the independent variables in laboratory studies can appear to account for large proportions of the variance (Fig. 5). This can result in an overestimation of the importance of the variable. Conversely, in the natural environment, with many other salient variables operative, the independent variable is only one of many influences. It may then only account for a small part of the total variation. This difference can lead to an overestimation of the importance of variables investigated in the laboratory and an underappreciation of the salience of variables observed in real-world contexts.

The regulation of water balance is an essential physiologic requirement. It occurs via the balance of intake with utilization and excretion. Laboratory research has established that excretion is curtailed and intake facilitated when fluid homeostasis is challenged by either an increase in plasma osmolality,69,70 or a decrease in blood volume.71,72 As a result, these stimuli have been postulated as the controlling influences on thirst. However, fluid intake usually occurs without any clearly defined deficit in either of these factors.73

We have produced evidence with the dietary-diary technique that fluid intake occurs in humans primarily in association with eating and that the amount and timing of fluid ingestion are determined primarily by eating.74 In addition, it was found that fluid intake and thirst in real-world contexts were not related to the depleting characteristics of ingested nutrients.75 Sodium intake, which would be expected to raise plasma osmolality and should increase thirst and fluid intake, was found to be unrelated to intake. In contrast, carbohydrate intake, which has only a very small osmotic impact and its metabolism results in the production of water, would be expected to be related negatively to fluid intake. In fact, the opposite was true, with carbohydrate intake being one of the strongest and clearest positive predictors of fluid ingestion. Hence, the observations of people ingesting fluids in their natural environment suggests that the two stimuli that were identified as the most important influences in laboratory research were in fact of little or no consequence in the control of everyday intake. In fact,
fluid intake seems to occur primarily in conjunction with eating, in excess of what is needed, and the remainder is eliminated in the urine. The fact that humans mostly produce copious quantities of dilute urine would support this contention. Phillips et al. observed water intake and the contents of the blood and the urine in healthy men during their working hours and could find no changes in body-fluid variables associated with the spontaneous ingestion of water. Hence, it would appear that, in the real world, unlike the laboratory, osmotic and volumetric stimuli are rarely influential in the control of fluid intake and thirst. Laboratory research resulted in a remarkable overestimation of the importance of these variables.

Another instance of a variable whose importance was overestimated in the laboratory is the hedonic pleasure derived from food, i.e., palatability. The hedonic properties of food have been shown in the laboratory to have a major impact on the amounts and types of foods ingested, with the amounts ingested markedly altered by manipulation of the flavor, texture, or appearance of food. However, in the real world, palatability has much less of an impact.

We investigated palatability influences on the ad libitum eating behavior by analyzing the 7-d diet diaries of more than 500 free-living humans. The participants recorded their intake and a global rating of the palatability of the entire meal on a 7-point scale. The results are summarized in Figure 6. Meals that were rated the highest in palatability were 44% larger than meals that were rated low in palatability (Fig. 6, right). This large impact is commensurate to that observed in the laboratory. However, it was found that most meals that are self-selected are palatable and that only 9.3% are rated as unpalatable, with ratings below neutral (rating of 4 in Fig. 6, left). As a result, the relation between palatability and intake only accounted for approximately 4% of the variance in meal sizes. These results were very similar to those observed for the French and suggest that palatability operates similarly on intake regardless of culture.

Palatability appears, from both the laboratory and the real-world analysis, to be a potent influence on intake. However, this analysis markedly overestimates its real impact on everyday ingestive behavior. It only accounts for a small fraction in the variance in the amount eaten. One reason for the seeming contradiction may have to do with a range restriction on the ratings produced by the self-selection of foods for ingestion in the natural environment. In the laboratory, the subject has much less control over the palatability of the food and unappealing food can be presented for ingestion. This can maximize the effect of palatability on intake. In the natural environment, this would rarely happen. People simply do not select to eat bad food. In fact, it might be argued that they strive to maximize the palatability of their meals. Hence, in the natural environment, there is less opportunity for the influence of palatability to be expressed. As a result, palatability appears to be only one, rather small, influence in complex array of many influential factors. Thus, palatability accounts for only a small proportion of the variance in intake.
Important Influences Can Be Missed Because of the Short Durations of Laboratory Studies

One of the drawbacks of laboratory research is the great difficulty in studying the behavior of the participant for any extended period. As a result, the vast majority of laboratory studies are very short term and involve only a few hours, at most, of study. This does not allow the researcher to view responses and adjustments that may entirely compensate for the effect of the manipulated variable. Real-world studies afford the opportunity to view behavior over a much longer time frame and thus can capture how the system reacts to and adjusts for short-term fluctuations in foods or the environment.

As an example, Raben et al. compared the effect of pregelatinized starch versus that of raw-potato starch in a test meal on plasma glucose, lipids, and hormones and subjective satiety. They found substantially lower hormone, glucose, and lipid levels after ingestion of the resistant starch. In addition, the resistant starch resulted in significantly lower sensations of satiety. However, when this manipulation was performed over a 4-wk period, total food energy and macronutrient intake were not affected. Hence, the manipulation that was effective in suppressing satiety on the short term had no impact on longer-term intake.

It is unusual for a laboratory research project to investigate intake for longer than a single day. As a result, compensation for intake of the previous day is not viewed or investigated, but this is important for the understanding of intake regulation. If the short-term mechanisms that are studied in the laboratory were the only mechanisms responsible for regulation, then the total amount of food energy ingested in a day would be relatively constant, provided that activity levels also were relatively constant. However, this is not the case because food-energy intake changes considerably from day to day. Hence, for regulation to occur, there must be a compensatory mechanism available to increase intake in response to a deficit from the previous day and/or decrease intake in response to a surplus from the previous day. Negative feedback from intake of 1 d must, in some way, occur to affect intake on subsequent days. This should produce a negative correlation between food-energy intake on 1 d and that ingested on the next day. However, the predicted significant negative autocorrelations have not been observed. They have been found to be small and predominantly positive.

We investigated this issue by using the daily intakes reported in the 7-d diet diary that we had obtained in previous studies. Autocorrelations were calculated between the amounts ingested in 1 d and each of the 4 subsequent d. As in previous studies, the correlations between food-energy intake on 1 d and that occurring on the next day were not significant. However, the autocorrelations with the 2- and 3-d delays were significant (Fig. 7). The 2-d lag autocorrelations were significantly stronger than with other delays. Interestingly, there appeared to be macronutrient-specific effects. Carbohydrate intake had a significantly larger negative correlation than did either fat or protein, with the amount of carbohydrate ingested either 1 or 2 d later. Fat intake had a significantly larger negative correlation than either carbohydrate or protein, with the amount of fat ingested either 1 or 2 d later. Similarly, protein intake had a significantly larger negative correlation than either carbohydrate or fat, with the amount of protein ingested either 1 or 2 d later. Hence, carbohydrate appeared to maximally affect carbohydrate, fat, and protein 2 d after ingestion. In addition, the individual macronutrients appeared to have macronutrient-specific negative feedback, with a 2-d delay.

Autocorrelation assumes that the error terms from each of the variables in the correlation are themselves uncorrelated. Violations of this assumption can result in an overestimation of the proportion of the variance that is accounted for by the regression. This assumption is nearly always violated with autocorrelations. However, using a simplex linear-structural modeling analysis that does not make this assumption supports the conclusions from the autocorrelational analysis that the negative effect of ingestion of a macronutrient is greatest on the subsequent intake of that particular macronutrient 2 d later. Hence, although there is a slight negative feedback that tends to restrain intake 1 d later, it is not until 2 d later that the effect is maximal. It continues on the third day but disappears by the fourth day. This interesting and important feedback mechanism was apparent only in the real-world data because of the ease with which extended time periods can be investigated.

In another example of the utility of the time periods available in real-world data, we were able to investigate seasonal effects on eating behavior. We simply looked at the daily intakes of participants who happened to be recording in the diaries during the four seasons. For most of the year, intake was not significantly different. However, in the autumn, intake increased by 11% to 14% compared with the other seasons (Fig. 8). This increase in overall intake occurred as a result of larger meal sizes, especially of carbohydrate. Once again, the utility of real-world data is evident for the exploration of events that are difficult to view with laboratory studies.

The Multivariate Richness of the Real World Is an Asset

The real-world environment contains a vast array of variables that influence intake. This can be viewed as a noisy environment that defies systematic analysis or as a rich mosaic filled with opportunities to discover surprising and unanticipated relations. The real world can reveal what is important. All the researcher has to do is observe and measure. There is no need to anticipate in advance what may or may not be important and then arrange the environment to isolate that factor. Rather, nature can be allowed to tell the researcher what is important.

The difficulty arises, however, with data from complex real-world environments in separating the influence of multiple inter-
Multiple regression can be used to investigate the independence of multiple variables influence on intake. For example, five variables that have been shown to influence intake—the time of the meal, the number of people present, self-rated hunger, the duration of the prior interval, and the stomach content—were used as predictors of the meal size. The univariate correlations are presented in the left panel of Figure 10. A multiple regression on these same variables as predictors of meal size produced the coefficients presented in the right panel of Figure 10.

Comparing the univariate with the multivariate outcomes, the number of people and hunger have essentially the same effects, which suggests that these variables affect meal intake independently of the other factors. However, the prior interval and the stomach content, which have highly significant univariate correlations, become nonsignificant factors in the multiple regression, suggesting that they are only seemingly effective variables because of their covariation with another factor. That factor would appear to be hunger, and this suggests that the duration of the prior interval is associated with meal size because the individual feels hungrier as the interval increases. Similarly, the stomach content appears to be associated with meal size because the individual feels hungrier as the stomach becomes emptier. Furthermore, the time of the meal, which was a nonsignificant univariate factor, becomes highly significant in the multivariate analysis. This suggests that the influence of time of day is suppressed by a negative covariation with another factor, possibly the before-meal stomach contents, and only after its effects are mathematically extracted does the true impact of time of day become apparent. This analysis demonstrates the value of using multivariate techniques on real-world data. The interdependencies and interactions between multiple factors can be sorted out, primary effect can be distinguished from secondary effect, and otherwise suppressed factors can be unmasked.

A final example of how the richness of the real-world environment can be used to detect subtle and interesting influences on intake regulation is the research on the inheritance of food-intake regulation. Because it has been well established that inheritance is a significant factor in the determination of body size, which is influenced by food intake, it stood to reason that food intake must in some way be affected by the genes. To investigate this idea, we studied the real-world intake behavior of free-living twins. Dietary nutrient intake data were collected for a 7-d period from 110 identical and 102 fraternal same-sex adult twins and 53 pairs of other-sex fraternal twins who were living independently. The diary entries were analyzed with linear-structural modeling techniques of heritability analysis. These techniques are sensitive, allow the assessment of genetic and early familial environmental effects, allow for the assessment of true sex differences in genetic and environmental effects, and allow the inclusion of other variables in the models to assess where in the complex interactive chains heredity affects the behaviors.

It was found that genetic influences permeate all aspects of ingestive behavior. Not only body size was affected by inheritance, but also the amount eaten and the macronutrients and alcohol composition were affected. In fact, 65% of the variance in daily energy intake, 44% of the variance in meal frequency, 65% of the variance in average meal size could be attributed to heredity. In contrast, the analysis indicated that the shared familial environments in which the twins were raised had no significant impact on the levels or pattern of intake in adulthood. A possible alternative explanation for these apparent genetic effects is that what is inherited is body size and that body size influences the amount of intake. However, linear-structural modeling showed (Fig. 11) that the heritability of daily food energy and macronutrient intake were independent of body size. Heredity accounted for 42% of the variance in daily intake even when the influence of body size was extracted from the model.

That there are genetic influences on the amounts ingested implies that in some way the levels of intake must be influenced or correlated influences. Fortunately, the development of multivariate statistical techniques can allow for the separation of these influences. The analysis of the effects of prior macronutrient intake on subsequent intake demonstrates how multiple linear regression can be used to separate effect. The before-meal contents of the stomach have a restraining effect on the amount eaten during the meal. This is indexed by a significant negative correlation between the food energy estimated to be present in the stomach at the onset of a meal and the meal size. In other words, the more there is in the stomach, the less food that will be eaten.

To examine whether the macronutrients have equivalent effects in restraining intake, we correlated the amounts of protein, carbohydrate, and fat that were estimated to be present in the stomach at the beginning of the meal with the meal size. These correlations are presented on the left panel of Figure 9. Clearly, all three macronutrients were negatively correlated with subsequent intake. Unfortunately, they were highly intercorrelated. When a large amount of food is present in the stomach, it is likely that there will be large amounts of each of the macronutrients and vice-versa with a small amount in the stomach. To look at the individual contributions of each macronutrient, we used multiple linear regression, where it is possible to view the effects of each while taking into consideration, and mathematically holding constant, the effects of the other two. The coefficients for the three macronutrients from the analysis are presented on the right side of Figure 9. Clearly, protein in the stomach has a large negative effect on intake, whereas carbohydrate and fat have little or no effect. This suggests that the effectiveness of the before-meal stomach contents on suppressing subsequent intake is due to the effect of protein and not of fat or carbohydrate. From the perspective of the current discussion, it is clear that multivariate statistics can be used to isolate and study individual variables within the complex intercorrelated matrix of influences present in real-world research.

FIG. 8. Seasonal rhythm of the mean total daily intake of food energy. The average intakes for the four seasons are double plotted to emphasize the rhythmicity.
regulated. Ultimately, the genes affect molecular and physical structure. However, we have obtained evidence that the genes may be also affecting the individual’s psychological state, the individual’s responsiveness to this state, and even the environment in which the individual is immersed and the individual’s reactions to the environments.29,33,37

The psychological appreciation of hunger is a case in point. How hungry an individual is at the beginning of a meal has a significant positive relation to how much will be eaten during the meal.34 It has been shown that the level of hunger, its correlation with meal size, and the slope of the relation are significantly heritable, with the genes accounting for 31%, 25%, and 27% of the mean, correlation, and slope, respectively.33 These results indicate that the genes have encompassing effects on this relation in affecting how hungry an individual reports to be, how well that hunger predicts meal size, and the degree of responsiveness of the individual to that hunger.

The estimated amount remaining in the stomach at the beginning of the meal has a significant negative relation with meal size.13,14 We demonstrated that the stomach content, its correlation with meal size, and the slope of the relation between stomach content and meal size are significantly heritable, with the genes accounting for 40%, 29%, and 45% of the mean, correlation, and slope, respectively.37 These results indicate that the genes also have encompassing effects on this relation in affecting how hungry an individual reports to be, how well that stomach content predicts meal size, and the degree of responsiveness of the individual to the level of stomach fullness or emptiness.

The number of other people present at the meal has a significant positive relation with meal size.30,31,40,62,66 It was shown that the number of people eating with the individual, its correlation with meal size, and the slope of the relation between the number of people present and meal size are significantly heritable, with the genes accounting for 20%, 27%, and 30% of the mean, correlation, and slope, respectively.29 This suggests that the genes affect all aspects of this relation in affecting how many people the individual eats with, how well that number of people predicts meal size, and the degree of responsiveness of the individual to that social facilitation.

The time of day at which a meal is eaten has a significant positive relation with meal size.32 It has been shown that the time of day at the beginning of the meal, its correlation with meal size, and the slope of the relation between meal time and meal size are significantly heritable, with the genes accounting for 37%, 21%, and 18% of the mean, correlation, and slope, respectively. This suggests that the genes influence all facets of this relation in affecting the time of day that meals occur, how well that time of day predicts meal size, and the degree of responsiveness of the individual to that diurnal rhythm factor.

The results of these behavioral–genetic studies indicate that significant genetic influences on food intake can be detected with real-world studies of normal free-living humans. The detected heritabilities involve a variety of aspects of intake regulation and suggest that there are subtle influences of inheritance that extend beyond the simple encoding of gross anatomy. The data imply that there are heritable factors that not only influence behavioral tendencies and preferences but also the individual’s responsiveness to environmental factors. This likely involves the inheritance of subtle nuances in the structures of the nervous system that underlie personal preferences, habits, dispositions, and sensitivities. These in turn affect the amounts of foods and fluids ingested.

**DISCUSSION**

It should be evident from this presentation that real-world behavior can be well measured and analyzed with self-reports. These tech-
Techniques are not without problems and errors. The diet-diary technique produces underreporting and reactivity that artificially reduce the estimates of the absolute values of intake. However, such phenomena as the inheritance of food intake, seasonal rhythms, and social facilitation can be discerned and analyzed with diet-diary data suggest that it is sensitive enough, even with the errors, to detect and document the influences of important and subtle variables on intake. The errors produced by the technique, when properly considered in the logical process of interpreting the data, are manageable and of less importance than previously thought. Hence, there is a simple, reliable, and valid methodology for studying real-world behavior.

It should be clear that there is a large number of influential factors that affect food intake in humans, including environmental, psychological, and social variables. It should also be apparent that these influences can be studied in normal humans who are living freely in their natural environments. The array of operative factors in the real world is not necessarily noise that contaminates the research; rather, it is a rich source of information on the nature and importance of real influences on eating. It is even possible to investigate causal linkages in real-world studies. By employing self-observational techniques and multivariate statistics, the complexity of the real world can be harnessed to produce a clearer understanding of the nature of intake regulation as it actually unfolds.

It should also be apparent that laboratory research does not necessarily lead to a clear understanding of the controls of intake. In the laboratory, many factors that tend to restrain eating are often removed or missing, which can lead to overingestion and an altered pattern of intake. Many real-world facilitatory influences on eating are controlled or removed in laboratory research, which can result in missing important variables in the control of intake such as daily, weekly, or even seasonal rhythms, expectancies, and social facilitation. As a result of removing, in the laboratory, many of the real-world sources of variance in intake, the importance of the studied variables such as palatability can be overestimated. This can also result in a misunderstanding of how intake is normally regulated as in the case of osmotic and volumetric thirst. In addition, the short durations of laboratory studies make difficult the detection of many important influences on intake that operate over longer time frames, such as delayed compensations or seasonal effects.

To some extent, this discussion has been an overstatement of the case for real-world studies. In fact, both laboratory and real-world studies are important in the unraveling of the complexities of food-intake regulation. Each has its strengths and its weaknesses; fortunately, the weaknesses of one type of research are often the strengths of the other. However, in the past, scientific analysis of food intake has overemphasized laboratory research and downplayed the importance or meaningfulness of real-world research. In fact, basic scientists often do not adequately value the results of real-world research because of the lack of the tight controls that scientists have been taught to treasure. What is needed is a balance, but, because the predominance of studies are controlled laboratory investigations, to achieve that balance, far more real-world research is needed. The primary underlying mes-

FIG. 10. The relationship of the meal size with the minute of the day of meal initiation, the number of other people present at the meal, the hunger self-ratings, the amount of time since the previous meal, and the estimated before-meal stomach content of food energy expressed as univariate correlations (left) or as mean coefficients from the multiple linear regressions (right).
The present treatise is that real-world research can be reliably and validly performed and that it can teach valuable lessons that are difficult to obtain in the laboratory.

From the perspective of the regulation of intake, the real-world data teach the lesson that intake is affected on the short term by a wide array of physiologic variables such as stomach filling and diurnal and seasonal rhythms, psychological variables such as hunger palatability, restraint, and expectancies, and social variables such as social facilitation and cultural influences. These factors can have potent and immediate effects on intake on a meal-to-meal basis. There are, however, long-term compensatory mechanisms that operate to provide negative feedback and adjust for prior excesses, but these compensatory mechanisms take 2 to 3 d to affect intake. The data also suggest that heredity affects all aspects of food-intake regulation, from the determination of body size to the subtleties of the individual preferences and social proclivities and the extent to which environmental factors affect the individual. Hence, the research on real-world eating behavior by humans has shown that it is an intricate, multivariate process whose understanding will require an appreciation for the totality of the context in which it occurs.

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FIG. 11. Linear-structural model and the most parsimonious model fitting the twin data for height, weight, and total daily intake are represented by the solid path lines and path coefficients. Dotted lines represent non-significant paths. For all remaining parameters, removing any one leads to a statistically significant reduction in the model’s account of the observations.

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