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Full Plate: Integrating Ingestive Behavior into Nutritional Science

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Abstract

I never expected to be a nutritional scientist. I developed an interest in ingestive behavior as an undergraduate in biology when mentors included me in research activities and directed me toward studies of the physiology of thirst for my PhD degree. While conducting basic studies on drinking behavior, my primary interests emerged. I wanted to study eating behavior to find effective strategies to improve food choices and manage overconsumption leading to obesity. Those studies started with animal models of obesity, but my interest in practical approaches to weight management led to studies in humans, the most difficult species to understand. With collaboration from colleagues, students, and staff, my team has characterized food properties that drive intake, including variety, energy density, and portion size. Studies aimed at understanding properties of food that influence eating behavior are now recognized as integral to nutrition, and I have found a natural home in this field.

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BEGINNINGS

Being asked to write an autobiographical article sent me into a spiral of procrastination as I contemplated which parts of my 60-year career in science to include. I looked up previous invited pieces and found inspirational stories of the challenges for women in nutrition and career accomplishments. What makes my story worth telling? I asked ChatGPT to summarize my career and found the result to be partially accurate, limited in scope, and painfully dull. On the other hand, when I mentor students or participate in "Meet the Professor" sessions, the conversation often moves to lively discussions on how a young investigator can build a career in nutrition. Since I walked a nontraditional path to nutrition, such questions have led me to reflect upon the breadth of what nutrition encompasses. The story of my career involves the integration of the study of ingestive behavior into the discipline of nutrition.

On reflection, I appreciate how my family background has influenced my trajectory toward nutrition. My paternal grandfather, Lloyd R. Simons, was professor and director of extension at Cornell. In 1942 he was appointed to the national committee on wartime extension work, where he helped farmers meet production goals. To me, he and my grandmother were simply avid gardeners. My father, Howard J. Simons, also a Cornell graduate, spent most of his career in Washington, DC, working for the US Department of Agriculture and helping to organize food for defense. Neither man spoke much about his work, or perhaps I did not listen, but their passion for food and nutrition seems to have been passed on. The women in earlier generations of my family were homemakers, which was the expected role. But in my generation, things shifted. Growing up in the 1960s, my peers and I were college-bound.

In high school I was a superachiever, serving as school president and lead pom-pom girl, along with receiving academic accolades, so the Ivy League was my target. At the time, only the University of Pennsylvania (Penn) and Cornell accepted women. Despite the family ties to

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Cornell, I chose Penn. That choice, although I could not have realized it at the time, shaped the rest of my career.

UNDERGRADUATE STUDIES AT PENN

Penn in the 1960s was the place to study eating and drinking behavior. I was a biology premed student and during my freshman biology class was captivated by the lively lectures led by Alan Epstein. I sought him out, and through that initiative, I was given the opportunity to work on a project on genetics in his lab. I loved being in the lab but was given an unrealistic view of how science worked economically. Alan was in demand. He showed me a file drawer packed with job offers. When we needed to have our fruit flies irradiated, he hired a private plane, and I flew along with the flies to the Brookhaven National Laboratory in New York. Those were golden days. Beyond the lab, Penn had a weekly Feeding Seminar, and I, an undergraduate, was invited to attend. That was the seeding of my career. Hearing leading scientists (Alan Epstein, Eliot Stellar, Philip Teitelbaum, Paul Rozin, Harry Kissileff) engage in friendly debate on erudite topics, including how to define motivated behavior, was inspirational!

At that time, I was planning to go to medical school. I knew I was inclined to do medical research and thought an MD degree would facilitate that better than a PhD. I look back on my self-confidence with wonder. I applied to only two medical schools, Cornell and Penn. I chose them partly because they did not require an essay—rather ironic for someone who ended up a *New York Times* best-selling author. I was accepted to both medical schools, and despite the lure of New York City, I stuck with the familiar and picked Penn Medicine. But I never went there.

During my final undergraduate year, a friend boasted that Alan Epstein was nominating him for a Thouron Award to study in England. Thinking I would be a better candidate, I stormed into Alan's office and demanded an explanation of why he had not nominated me. The reason was that, at that time, the award was only for men. We changed that, and I was in the first wave of women to be sent off with a Thouron Award to "promote Anglo-American affairs."

Around the time that I was set to travel to England, Alan had met James Fitzsimons, a British professor, and the two were eager to collaborate. I became the link between them, with a bench in the Physiology Department at the University of Cambridge. My bench was in a small office shared with James and our test subjects (rats). In the British system, undergraduates had already specialized in their chosen discipline, so as graduate students they just needed to get on with their research. I overcame my lack of experience by attending undergraduate physiology classes and by giving tutorials to classmates, which was a challenging way to learn.

CAMBRIDGE AND RESEARCH IN PHYSIOLOGY AND THIRST

I have described my early career studying thirst in a previous piece (48). Here, I give a few highlights. I arrived in Fitzsimons's lab when he was at the peak of his research career. He had recently discovered that the kidney not only regulates fluid output but also stimulates thirst via the release of renin/angiotensin as blood volume decreases (20). During my first year, James involved me in his ongoing studies of intravenous angiotensin and thirst (21).

By my second year I had given up my place at Penn Medicine to continue pursuing a PhD in physiology at Cambridge. During that second year, James took a sabbatical with Alan at Penn. At the end of that year, I joined them briefly, and together we demonstrated that the injection of angiotensin into a rat's brain caused a specific drive for water and avid fluid intake (18).

While James was on sabbatical, I was left on my own to experiment. Administrative hurdles were minimal then, so I could test new ideas freely. Looking back, it was daunting but exciting. The department's faculty adopted me; after all, I was their first female doctoral student. A major

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highlight of that year was the thrill of publishing my first paper, a single-authored research letter to *Nature* on diabetes insipidus and the role of antidiuretic hormone in thirst (73).

OXFORD YEARS: MOVING CLOSER TO THE NUTRITIONAL SCIENCES

A year later, I had completed my PhD and was planning the next step. I was engaged to marry Edmund Rolls, then a psychology graduate student at Oxford University, so I looked for opportunities there. David McFarland, a noted animal behaviorist, offered me a position in his lab in the psychology department, but I needed to find my own funding. I was fortunate to be awarded the prestigious Mary Somerville Research Fellowship, later learning that I was the first American to ever receive it. I credit that success to my ability to convey the significance of my work. One advantage of studying ingestive behavior is that people are inherently curious about it, making it exciting to communicate.

I spent the next 15 years in the Department of Experimental Psychology at Oxford University. Within a year of arriving, I was running my own lab. David McFarland moved to zoology, and I inherited all of the space previously allocated to him. During that time, I held a number of research fellowships, all short-term, soft-money positions. For more stability I accepted a tenured faculty position at Oxford Polytechnic (now Oxford Brookes University) while keeping my lab at Oxford University. This turned out to be challenging, as some weeks I was doing 14 hours of classroom lectures along with the research, while also being a mother of two babies under the age of two. Sometimes you have to acknowledge that you cannot do it all. After several years, I decided that a tenured position was worth keeping only if you wanted or needed the job long-term. I resigned from the Polytechnic and risked being back on soft money. The risk paid off, and during the rest of my time at Oxford University I had research funding from a mix of government, foundation, and industry sources.

Fortunately, although I was untenured, I was able to mentor doctoral students. I was eager to extend our basic studies on thirst in animal models to humans, and one of my first doctoral students, Paddy Phillips, who had an MD and who later became chief medical officer for South Australia, made that possible. Our team described the body fluid changes and subjective sensations that accompany overnight fluid deprivation and subsequent rehydration (71). Paddy also measured determinants of ad libitum thirst by shadowing participants over a normal day. We found that participants became thirsty and drank before body fluid deficits developed. This anticipatory thirst was related to oropharyngeal cues such as a dry mouth (40).

We followed this novel finding with basic mechanistic studies showing that angiotensin (37) and hypertonic saline increased water intake in humans (38). In our most prominent study, published in the *New England Journal of Medicine* (39), we found that older men were less thirsty and drank less after water deprivation than younger men. Alas, aging affects even our most fundamental motivations. These basic studies of thirst accelerated my path toward being considered a nutritional scientist.

Another of my students at Oxford, Marion Hetherington, now professor emerita in biopsychology at the University of Leeds, brought me even closer to nutrition. She helped to build on studies that I had been conducting in undergraduate laboratory classes (25, 58, 59). Animal experimentation was restricted in teaching, while simply feeding students was fine. The key studies that came out of this need to have productive undergraduate lab classes demonstrated that satiety in humans is food-specific (69). Our experiments consistently showed that, as a food is eaten, liking for it declines, while other foods, particularly those with different sensory properties, remain palatable. This "sensory-specific satiety" promotes consumption of a variety of foods and

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thus helps to ensure that we consume a balance of nutrients (70). However, in a food environment characterized by excess, variety can encourage overeating and contribute to the development of obesity (50).

Our work on variety attracted a lot of attention, not all of it positive. An Oxford group of antivivisectionists gave me a "Golden Fleece Award" for studies showing "what everyone's grandmother already knew." The idea that everyone knows what drives eating—after all, we do it multiple times a day—remains pervasive to this day but is unfounded. The importance of gathering empirical evidence to support hypotheses is critical and is overlooked in those arguments. Furthermore, it is often harder to conduct well-controlled studies in humans than in other species. Large individual differences in culture, context, and economics add enormous variability to study outcomes. Nevertheless, with the devastating effects of eating disorders and the epidemic of obesity there is an urgent need to understand what drives consumption.

RETURNING TO THE UNITED STATES: THE JOHNS HOPKINS YEARS

Interest in our studies led to invitations to speak at international meetings. During my travels I met many leading scientists who remained friends, and some became important collaborators. Such networking introduced me to Paul McHugh, head of the Department of Psychiatry and Behavioral Sciences at the Johns Hopkins School of Medicine. I was divorced and ready to move back to the United States when he recruited me, so timing was on my side. I became an associate professor in psychiatry in 1984 and was on the tenure track, although tenure there meant continuing to raise your own salary through grants.

While Hopkins would provide an exceptional environment for our studies of eating behavior, moving internationally was challenging. I had no US credit history despite being American, and I could not move my grants. Thus, I had to "start from scratch" and identify sources of support. My first American grant was from the Sugar Association for basic studies comparing the effects of sugar and aspartame on intake. We found that when participants could eat as much as they liked of a dessert sweetened with either sugar or aspartame, they ate similar amounts of both and thus energy intake was less when served the aspartame-sweetened foods (61). This early observation that individuals consumed a rather constant amount of food despite variations in the energy content led to our later studies that focused on energy density as a factor driving energy intake. It also led a reporter to express astonishment that the study had been funded by a sugar organization, as the results suggested a benefit of the sugar substitute. An important message here is that it is possible to publish unbiased research supported by the food industry, and we should not overlook this source of funding. I have always enjoyed working with industry, as such work provides insights into practical consumer issues that our research can address.

MACRONUTRIENTS AND INTAKE

Until this point, my research had helped to blur the lines between physiology, psychology, and nutrition. During my next eight years at Hopkins, our studies on eating behavior were clearly within the scope of nutrition. During the 1980s, debates about macronutrients were central to the field and a major media topic. Low-fat, low-carb, and high-protein diets were each promoted as a solution for weight management, yet few studies had systematically compared how these nutrients affected satiety and food intake. I was now starting to investigate such nutritional issues, but from a behavioral perspective.

With funding from my first federal grant, awarded by the National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK), we conducted a series of studies comparing effects of fat (any fat) and carbohydrate (often sucrose) on satiety and intake over single meals (60) or over

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multiple days in a residential facility (22). Along with dose–response effects, we examined the time course of satiety (47) and even tested effects of intragastric and intravenous infusions (72) of fat and carbohydrate. What became clear was that, when both palatability and energy density of the food stimulus were controlled, fat and carbohydrate did not consistently differ in their effects on satiety. This finding shifted my focus: perhaps it was not the macronutrients driving intake, but rather the energy density.

At the time, high-fat foods were thought to encourage overconsumption through their palatability or influence on gastrointestinal or metabolic mechanisms. Yet the high energy density of fat relative to the other macronutrients, 9 kcal/g compared with 4 kcal/g, was often overlooked. Classic studies had hinted at its importance, as had our early studies (61). For example, in the 1970s, cloistered nuns maintained similar food intakes when fed diets with very different fat percentages but matched for energy density by adding water (79). Later, Roland Weinsier and colleagues showed that lowering energy density by emphasizing fruits, vegetables, and whole grains while limiting fat and sugar led participants to cut their energy intake nearly in half, while still feeling satisfied (14).

These studies point to a role for energy density in food intake regulation, suggesting that countering the high energy density of fat by the addition of water or water-rich ingredients was a primary determinant of intake. Water, which adds weight and volume to foods, has 0 kcal/g and can be used strategically to moderate the effect of fat on overall dietary energy density. Using population-based data, we have shown that a high-fat diet that includes a substantial water-rich component can be lower in energy density than a low-fat diet with few vegetables and fruits (30). Such insights have led us to conduct multiple studies confirming that energy density is an important, and often primary, influence on energy intake (2, 52). I return to this topic below.

THE MOVE TO PENN STATE

In 1992, I was recruited to the endowed Shibley Professorship of Biobehavioral Health at The Pennsylvania State University (Penn State). By now I was a tenured full professor at Hopkins, so why would I leave? While Hopkins was an excellent environment, it would always be soft money. As a single parent, that insecurity was unsettling. Also, mentorship opportunities in the medical school were limited. I wanted more security, and I wanted to mentor students—Penn State offered both.

Mentorship, whether through teaching or research, has become what I enjoy most, and what I hope will be my legacy. Most of my formal teaching at Penn State has been in graduate courses. In the now legendary Nutrition 520 course that I have taught for the past 25 years, all first-year nutrition graduate students learn the basics of becoming a scientist and of presenting research. Former students whisper to one another when at meetings listening to a mediocre talk, "They should have done 520!" Watching the students in my own lab come to appreciate the joy of discovery, develop excellent writing skills, and grow into confident, successful professionals has been my proudest achievement. Graduates from our program have helped to spread the study of ingestive behavior to multiple nutrition departments.

Brainstorming with students and colleagues has helped me be more creative than I can be on my own. This has worked well during my time at Penn State, as we have a cluster of faculty and students studying ingestive behavior and obesity. Leann Birch came here at the same time as me. Together we started the Ingestive Behavior Seminar, which I continue to lead with Kathleen Keller and John Hayes. Each week, we have a lively discussion, and the class shows students that science is fun and especially productive when we engage in friendly debates.

Let's get back to the original question of how my career trajectory led me to nutrition. While my research in ingestive behavior was clearly nutrition related, my home academic departments

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continued to be nutrition adjacent. I had traded physiology (Cambridge) for experimental psychology (Oxford), psychiatry (Hopkins), and biobehavioral health (Penn State). As with so many things in life, serendipitous circumstances propelled the move to nutrition. My house in State College was two doors away from John Milner and his wife, Mary Francis Picciano. If you knew them, then you know that they both had very persuasive personalities. As soon as I arrived at Penn State, John told me I belonged in nutrition. He was head of the department, and they had a prestigious position to fill: the Helen A. Guthrie Chair, named after a female legend in nutrition. John was insistent that my research on ingestive behavior fit in nutrition and that I was perfect for the role. He wore me down, and after three years at Penn State, I moved to Nutritional Sciences as the Guthrie Chair. John's vision that studies of ingestive behavior should be foundational in nutrition has had a long-standing impact on nutrition at Penn State, where we remain among the best places in the world to study eating behavior.

Although I was now firmly in nutrition, it was clear that behavioral aspects of eating such as learning, visual cues, information, and context needed more attention. Foods must first be selected and eaten before their nutrients matter. We knew from work conducted during my time at Oxford that the variety of available food choices could be a determinant of intake. What other food properties were likely to also play a role? The next few years (the late 1990s to the early 2000s) turned out to be a time of rich discoveries for my lab. We conducted fundamental studies on what I now describe as "The Big Three" properties of food that drive intake (56). Along with effects of variety, we added portion size and energy density as established and, indeed, more consistent influences on intake compared with other proposed properties such as the proportions of macronutrients.

DEMONSTRATING THE EFFECT OF ENERGY DENSITY ON INTAKE

Most of the studies my lab conducted on the macronutrients had focused on satiety, or the effects of a first course (preload) on later consumption. It was when we continued doing studies of ad libitum eating, or satiation, that a robust pattern in intake behavior emerged. As I noted earlier, we had observed that, when allowed to eat ad libitum, participants consumed a consistent amount of food when we varied the energy density of desserts and, thus, consumed more calories with the higher energy-dense option (61). This suggested that the energy density of foods is an important driver of energy intake.

It was time to focus more deeply on the impact of energy density on intake. Our first major study that aimed specifically to study energy density took months to design (2). The plan was to separate the effects of energy density from variations in the proportions of macronutrients and palatability by varying the water content. Our focus on getting the test foods "perfect" was relatively new in studies on eating behavior and has remained a priority for us. We found that to vary energy density, mixed dishes such as casseroles worked well. We could swap out water-rich ingredients such as vegetables for pasta and meat to manipulate energy density without altering palatability. Every ingredient had to be finely chopped so that participants could not pick through and select only their favorite parts. For the first study (2), we formulated enough different dishes for two days of measured intake. Across conditions, we tested foods with three levels of energy density that were all similar in palatability and macronutrient proportions. We found that when instructed to eat as much as they liked, over the two days participants ate a consistent amount by weight. Because energy density varied by 30% across conditions, their energy intake also varied by 30%. Crucially, hunger ratings did not differ, and no compensatory eating occurred (2). This and subsequent studies confirm that the energy density of the available foods is a primary driver of intake (4, 52). Whether in short-term lab studies or longer-term interventions, lowering energy density reliably reduces energy intake without increasing hunger (45, 49, 84).

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WATER: ITS INFLUENCE ON FOOD INTAKE

Let's continue the discussion of water. It is an often overlooked and understudied influence on food and energy intake. While we had shown that increasing the water content of foods to lower energy density reduced energy intake, we wanted to know if drinking water would have a similar effect. Drinking water before or during a meal is often promoted for weight loss, but its efficacy is unclear. We studied this by varying the first course served at lunch. These preloads included one in which water was consumed as a beverage along with a casserole and another in which water was combined with the casserole to make a soup. When the women ate their next course, the consumption of water reduced intake only when it was incorporated into the casserole to make a soup. Water consumed as a beverage did not affect subsequent intake (53).

There are several possible explanations for why the soup was the most satiating. Adding water to the casserole made the portion of food bigger, which may have influenced expected satiety and sensory-specific satiety (3). Studies from colleagues have also found that water bound into food empties from the stomach slower than water as a beverage (33). My takeaway message from this is to "eat your water" if you want to reduce food intake. Drinking water will primarily affect thirst mechanisms rather than hunger. I still hear people swear that drinking water before or during a meal fills them up, and if they believe it, perhaps it will. Such anecdotal declarations have some limited experimental support (6, 12). However, I urge caution in thinking that consuming water at a meal will lower food intake. We recently found that drinking water could increase intake during a meal if diners frequently switch between taking sips of water and bites of food (9). Switching can prolong the meal and delay the development of sensory-specific satiety leading to meal termination.

A frustration that I have when working to understand the role of energy density in intake is that assessing it is not easy. Accounting for water in diets adds complexity to both the assessment of self-reported intakes and to controlled interventions. In population-based studies, it is difficult to account for the water content of foods since it varies considerably between recipes, products, and cooking times, which affect water evaporation. In lab-based studies, we can control such variables, and my lab became expert at this. Some studies that claim to have controlled energy density fail to realize that a small difference can have a large effect. For example, a difference of just 0.1 kcal/g/day could result in daily intakes that vary by several hundred calories (29). Thus, incomplete matching of energy density can confound effects of intentional variations in other food properties.

I was fortunate that in the early 2000s, the Centers for Disease Control and Prevention (CDC) had an active research program related to diet. They funded a postdoctoral fellow in my lab, Jenny Ledikwe, and with them we explored methods to calculate energy density and its relationship to weight status in population-based data (29). Nutrient analysis programs were not designed to easily calculate energy density, nor was there a standard method for these calculations. It was unclear whether to consider energy-containing liquids (e.g., milk, juice, alcohol, soup, meal replacements) as a food or a beverage. To explore the best method, we calculated energy density with eight different combinations of foods and various types of beverages and found in that first study (29), and those that followed (80), that the clearest association of energy density with weight status was when the calculation represented nonbeverage intake consisting primarily of solid foods. Unfortunately, this is another aspect of energy density that is often overlooked.

The failure to consider the impact of beverages when calculating dietary energy density, along with the impact of very small variations in energy density on intake, has likely led to the misinterpretation of the results of multiple clinical trials. For example, the heavily cited study on effects of ultraprocessed foods on intake and body weight allowed an almost twofold difference in the nonbeverage (food) energy density (24). The 500 kcal/day increase in intake across the 14-day study was likely driven in large part by this difference in energy density rather than the degree

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of processing (55), a conclusion reinforced by the group's more recent studies (19). Another widely publicized trial comparing effects of ultraprocessed foods with minimally processed foods on body weight over eight weeks similarly failed to account for the influence of energy density, making it impossible to attribute outcomes to the level of processing (13). Trials designed to compare effects of different diets on intake and body weight either need to match nonbeverage energy density across conditions or, if that is not possible, should assess the role of energy density, using recommended methods for their calculation (29).

EVIDENCE SUPPORTING THE ROLE FOR ENERGY DENSITY IN WEIGHT MANAGEMENT

As mentioned, studies of single meals or over multiple days demonstrate the robust and significant effect of energy density on intake. A key question is whether shifting to a healthy eating pattern that encourages individuals to lower the energy density of their diet will facilitate weight management.

As I considered how to address this question of energy density's role in weight management, given that I was used to conducting controlled, short-term, lab-based studies, luck was on my side. In the lab next door was my colleague and friend Penny Kris-Etherton, who is renowned for her long-term trials on dietary influences on cardiovascular health. Together we conducted a year-long trial to compare the incorporation of either a low-energy-dense food (soup) or a high-energy-dense snack food into a reduced-calorie diet. We found that the reduction in dietary energy density was the main predictor of weight loss during the first two months of the study and that over a year daily consumption of soup increased the magnitude of weight loss (64).

In another year-long clinical trial our primary aim was to compare weight loss in response to two energy-density reduction strategies: reduced-fat or reduced-fat plus positive messages to increase low-energy-dense foods such as vegetables and fruits. We found that after a year, participants in the group that focused on eating more low-energy-dense foods lost more weight, had a lower dietary energy density, consumed a greater weight of food, and reported less hunger than participants who focused just on fat reduction (15).

In 2004, I was invited to be an expert presenter on energy density at a Dietary Guidelines Advisory Committee meeting. At that time there was little evidence from randomized trials, and it was not until 2010 that energy density was evaluated for inclusion in the guidelines (36). However, for me some good came from the meeting. Lawrence Appel, principal investigator for the multicenter PREMIER trial testing different dietary patterns for weight loss and blood pressure control, was at the meeting and approached me to ask whether we (the team at the CDC) would be interested in assessing whether energy density affected the trial outcome. Even though participants in one arm had followed the Dietary Approaches to Stop Hypertension (DASH) diet and been encouraged to eat more vegetables and fruit, they had not lost significantly more weight than other arms receiving standard diet information (1, 16). An important message here is that the advice a participant is given does not predict the extent to which they will comply or change the energy density of their diet. Indeed, compliance varied across the study arms, and we found that when we combined data from all three arms, the decrease in energy density after six months was the strongest predictor of the amount of weight lost (31). Thus, the adoption of strategies that lowered energy density had a greater impact on weight loss than the specific dietary advice given to the intervention groups.

Nutrition is often dominated by advice that distracts from evidence-based findings. For example, the current focus on lowering the availability and intake of ultraprocessed, hyperpalatable foods should emphasize that most are high in energy density, and that lowering energy density should therefore be a goal. In 2004, my lab wrote a response to a request from the Food and Drug

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Administration (FDA) for suggestions to clarify the nutrition facts label. We proposed that the inclusion of a standard measure of a food's nutrient/calorie content per 100 grams would improve the label's ability to assist consumers when making food choices. We pointed out that most other countries already included such information on their labels. After our advice was ignored, a senior FDA employee assured me that consumers would not understand calories per 100 grams. I still maintain that such information would make it easier for consumers to compare products to determine, for example, which gives them the fewest calories or the most of a particular nutrient in a standard portion.

Understanding energy density would also help consumers follow the current Dietary Guidelines for Americans (78) and evidence-based healthy diets such as the Mediterranean diet that advocate eating patterns that reduce energy density (76). Such patterns include high intake of fruits and vegetables, fiber-rich foods, and adequate proteins, while discouraging intake of foods high in added sugars. Several clinical trials and commercial weight loss programs likely owe at least part of their efficacy to a reduction in energy density. We have reviewed these programs elsewhere (84); here, I highlight several examples.

ENERGY DENSITY IS A COMPONENT OF SUCCESSFUL WEIGHT MANAGEMENT PROGRAMS

Although it is not widely recognized, reductions in energy density have been a key component of many successful weight management programs. At the forefront is the long-running EatRight® Weight Management Program developed by Roland Weinsier in the 1980s as an academic weight loss program aimed at lowering dietary energy density (82). Roland's innovative studies demonstrating the powerful effects of energy density on intake were foundational for my studies on energy density.

Another example is the Look AHEAD trial designed to test both pharmacologic and lifestyle strategies for weight and glycemic control among individuals with type 2 diabetes. The lifestyle intervention included strategies to reduce dietary energy density (23). The trial originally planned to include a low-fat approach, but before the trial started, there was a pivot to the Volumetrics diet and an emphasis on lowering energy density. I personally purchased hard-copy versions of my first book on Volumetrics (51) for distribution to each participant. Many lost weight and kept it off, but as is often the case in weight-loss trials, the energy density of the diet consumed was not assessed (81). Such assessments could help to resolve debates about which dietary components are critical determinants of weight loss and maintenance (84).

Often, commercial weight-loss programs incorporate the principles of energy density, and over the years I have consulted for many of these companies. Several have published data that indicate a positive role for energy density in their programs. An examination of data from participants in the Slimming World program in the United Kingdom showed that low-energy-dense meals improved appetite control and that this likely contributed to the success of the program (5). Data from another program, Noom, showed that changes in patterns of intake favoring consumption of a greater proportion of low-energy-dense foods were associated with weight loss after 18 months (34). Teaching individuals the principles of energy density and strategies to leverage energy density to guide food choices and intake could be key to enhancing weight management in both clinical practice and commercial programs.

ENERGY DENSITY AND THE SKEPTICS

When I first presented our results on energy density, there was a mixed reaction of enthusiasm for the new and skepticism from the entrenched. Going through memorabilia from that time

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reminded me of the 1997 Food and Agriculture Organization meeting in Rome where I presented early data on energy density. During my talk, several of my colleagues walked out in protest of the findings. Since then, multiple studies have provided evidence that energy density is a primary driver of intake (36, 41, 84).

While I am pleased that there is a significant body of evidence to support a role for energy density on intake, I continue to be frustrated by the reluctance of some influential members of the nutrition community to acknowledge its importance, especially for weight management (32). The effect of energy density on intake is robust. I urge skeptics to examine the evidence and to consider the benefits of incorporating messages about energy density into dietary guidance. After all, it promotes a higher-quality diet as it depends largely on increasing the water content of foods (adding more water-rich foods such as vegetables and fruits) along with a reduction of intake of unhealthy fats. Increasing the proportion of low-energy-dense foods allows people to eat satisfying portions while managing their energy intake. My advice to my colleagues who study dietary effects on intake and body weight is that you must account for energy density or you could misinterpret your findings. In my 60 years of studying ingestive behavior, I have not found a stronger influence on food intake.

Perhaps it is difficult for those who have focused on the biological effects of foods and nutrients to embrace the behavioral aspects of eating. This thought brings us back to the theme of this story: "Where does behavior fit into nutrition?" Decisions about how much to eat likely rely on previous experience. Usually, we do not know the energy density of the foods we are eating, so we choose portions based on what we have learned about a food in terms of how filling it is and if it is an appropriate portion. Visual cues also come into play. Simply changing how a food looks by aerating it (35, 54) or changing its shape (62) affects how much people serve themselves and consume. When people choose how much to eat based on previous experience or visual cues, they should understand how the density of calories in their portion affects their energy intake.

ENERGY DENSITY AND PORTION SIZE COMBINE TO AFFECT INTAKE

Our early studies of energy density overlapped with those we conducted on portion size. In 1995 we successfully demonstrated an effect of portion size on intake when we served army men three different portions of macaroni and cheese. We presented the findings at The Obesity Society meeting (17), but a colleague lost the data before we composed the manuscript. Finally, in 2000 we published our first peer-reviewed paper demonstrating an increase in intake in response to increasing food portions (57). I regret the messaging from this study, which found that the portion size effect was evident in older (five years of age) but not younger (three years of age) children. This was interpreted as support for the idea that younger children self-regulate their intake; however, our more recent studies in preschool children counter this suggestion (74, 75). Most notably, when we tested the response to portion size over five days in three-to-five-year-old children, there was a clear effect of portion size on intake that was observed from the first day, persisted over the five days, and was not influenced by age. Rather, across children, the effect was largest for foods highest in energy density, and the higher the child's weight status, the more responsive they were to the portion size effect (74).

Over multiple studies, we and many others have shown that the effect of portion size is robust (63), is persistent (67), and occurs across a range of foods in both adults and preschool children (56). It can be used strategically to increase intake of underconsumed foods such as vegetables. We have shown that the advice to increase the proportion of vegetables and fruits served can improve their intake, especially if they are relatively palatable compared with competing foods (42, 43, 68).

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An emphasis on portion control has been fundamental to most approaches to weight management, but its contribution was not well understood. In a year-long clinical trial, we tested the efficacy of three different strategies: (*a*) eat less overall, (*b*) use measurement tools to manage intake of energy-dense foods, and (*c*) use preportioned foods. The preportioned foods group lost the most weight over the first several months, likely because they were provided with much of their food and did not have to learn new ways to manage portions. However, by the end of the year all three groups had lost similar and significant amounts of weight (65).

After the trial ended, my then doctoral student Faris Zuraikat tested some of the women from the trial to determine if the strategies they used to manage portions persisted beyond the intervention (83). At test lunches varying in portion size, the women ate more from the bigger portions, indicating that the portion size effect was robust and persistent even after intensive education. The good news is that they chose a greater proportion of the lower energy-dense options, which helped to counter overconsumption stemming from the large portions. This study emphasizes that a key to managing the effect of large portions is to choose foods lower in energy density so that the plate can still be full.

THE COMPLEXITY OF EATING BEHAVIOR

Over my career most of the focus has been on isolating factors that influence intake to characterize them and test how robust they are. Now multiple studies confirm that the Big Three—variety, energy density, and portion size—are key determinants of energy intake (56). Since meals often vary in these properties simultaneously, we began studies to better understand their combined effects. We found that concurrent reductions in energy density and portion size led to a 56% decrease in energy intake over two days in adults (66) and 79% at lunch in preschool children (27). Paige Cunningham, a former doctoral student, showed that the size of the portion served also combined with the variety of food options at a meal (10), and colleagues have shown robust increases in intake when foods are both high in energy density and easy to eat quickly (28, 77). With her interest in the complexity of eating, Paige and our team developed a theoretical "Satiation Framework" (11) based on a new questionnaire, the Reasons Individuals Stop Eating (the RISE-Q), which will help develop hypotheses related to meal termination for further experimentation (7, 8).

The combined effects of all of the Big Three properties (56)—energy density, portion size, and variety, which are common characteristics of an obesogenic environment—have not yet been tested. Future studies will show whether, when combined, these food properties act independently and how systematically varying them influences intake. The findings will lead to better understanding of how we can use properties of foods to promote satiety and counter overconsumption. It will be particularly interesting to determine how these properties affect intake when people are taking the various antiobesity medications currently available and in development. Such studies will provide insights into interactions between behavioral responses to foods and biological mechanisms.

DISSEMINATING SCIENCE

While I was a graduate student, I made multiple outlines of the book I wanted to write on diet and eating behavior. Some working titles were *Need or Greed* or *Through Thick and Thin*, which, thankfully, were left behind. My desire to spread advice about weight management started in my childhood home. My mom had obesity. She blamed her weight on eating to keep up with the large amounts my naturally thin dad ate. In that environment, I did not learn how to choose nutritious foods or how much I should be eating. My first forays into living away from home led to weight gain followed by multiple fad diets. Such lived experiences encouraged me to disseminate information about the science of eating behavior.

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In the context of my academic career, I am hesitant to talk about my life as a "diet guru," but since this is an autobiography, I will reveal a bit about the experience. With my urge to communicate, I had decided to try to enter the mass-market publishing world. I had plenty of experience with the media through their interest in our research but knew nothing about the book world. In the late 1990s, I finally got moving on the book that I had wanted to write since my student days and was lucky that that was a time when people relied on books rather than social media for dietary advice. I learned that to get started you needed a compelling proposal that a publishing house would purchase. Before you could reach a publisher, you needed an agent, and agents are particular about who they want to represent. It helped if you were already well-known or had a novel approach.

I put the first Volumetrics book proposal together with a writer who already had an agent who was interested in our ideas. She was ready to sell our proposal to publishers when the TV show *20/20* was putting together a piece on diets. This was 1999, and the first diet they planned to cover was the Cabbage Soup Diet. They wanted to feature several other diets, and somehow they heard about ours. Thus, the adventure of authoring a popular diet book began. Soon my lab was filled with the film crew recording the show. It aired the day before the book proposal went out for bids. HarperCollins made the winning offer, and we were set to begin. I can assure you that this smooth path to publishing is unusual.

As my adventures with Volumetrics began, the risks involved now loomed. Diet book authors are often perceived as little more than snake oil salesmen. Even when you take an evidence-based approach, it is difficult to translate findings from controlled studies into practical advice. This is especially true for nutrition since our studies have so many potentially influential variables. My experience has taught me that readers want to know limitations of the science as well as the challenges associated with making behavioral and dietary changes. I also learned that books do not sell themselves.

Fortunately, my first two books in the Volumetrics series (44, 51) were released when traditional media such as television, radio, and print were still the norm and the publisher organized most of the promotions and book tours. My first promotional appearance was in a bookstore in a large mall outside Philadelphia during a blizzard. Only one person came and that was because her employer, a food company, required it. Despite that rocky start, I mostly enjoyed interactions with the media as they gave me opportunities to convey to the public the research that shaped the books. By the time the third book in the series was published in 2012 (46), the book world had changed. Publishers left it to the author to do the promotions and to rely on social media. I was not then, and still am not, active on social media.

As Volumetrics gained in popularity, it was briefly number one on the *New York Times* list for nonfiction, and it continues to be rated by *U.S. News & World Report* as one of the top diets for weight loss. Several organizations adopted energy-density principles in outreach; among these were the American Institute for Cancer Research, the CDC, the British Nutrition Foundation, and The Obesity Society. I feel that I have met the primary goal of my books, which is to educate consumers on how to recognize and manage the properties of food that are influencing their intake.

Overall, I am glad I took the risk of publishing a book for consumers. I know that my books were based on the best evidence at the time. The gratitude from those who have had success using Volumetrics makes the endeavor particularly meaningful. Worth noting is that a number of the success stories came from physicists who appreciated knowing how energy density affects how much they could eat! In this era of underappreciation of science, we must convey to the public the relevance of our studies. But, if you ask me if I want to write another book, my answer is no. The challenge of communicating via social media is daunting. I leave that to those of you who enjoy that type of outreach to convey the pleasure and benefits of healthy eating.

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WRAPPING UP

As I move toward retirement, I am pleased that nutrition at Penn State will continue to include an emphasis on ingestive behavior and obesity. I continue to collaborate with Kathleen Keller, now my successor to the Guthrie Chair. She and her team have found that certain brain and behavioral responses to portion size appear to be part of a phenotype that can help predict the development of obesity in children (26). I also continue to work with current and former graduate students who are determined not to allow me to fully retire.

Over my career I have had enormous fun designing studies to understand the attributes of food that influence eating behavior and how to apply this knowledge to effective dietary strategies for weight management. I tell my students, when they complain that I did all the "easy" studies, that there are still many questions to ask. We need a broader focus on cultural and contextual aspects of eating behavior as well as its complexity. Methods that were fantasy when I started my career will potentially lead to better understanding of the biological mechanisms underpinning eating behavior and how to leverage these to direct people to more nutritious food choices.

While I tell my students not to apologize when discussing their accomplishments, I feel I must. This is not a comprehensive review, but rather, a personal account of how my career evolved. I am able to cite only a few of the studies that influenced my thinking and cannot personally acknowledge all of the many people who have assisted me on this adventure. I have summarized 60 years of study, and I hope to have convinced you that behavioral studies belong squarely within the nutritional sciences. I must thank all of my colleagues, postdocs, students, and staff who have done the work and kept the ideas flowing. I always feel smarter when I am with them. Our labor-intensive studies (during our last NIDDK-funded grant we fed preschool children more than 10,000 measured meals and snacks) would have been impossible without them.

I want to acknowledge three of my former students who have given me input on this essay: Marion Hetherington, Professor Emerita at the University of Leeds; Faris Zuraikat, Assistant Professor of Nutritional Medicine at Columbia University; and Paige Cunningham, Assistant Professor of Nutritional Sciences at Cornell University. I continue to collaborate with them, and with this account they have had the opportunity to turn the tables and edit my writing. Just what a mentor wishes for!

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The author receives royalties from the Volumetrics books and is a member of the McCormick Science Institute Advisory Board.

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