Holiday greetings from Nutritional Sciences. As we near the end of the fall semester, it’s time we can look back on the great experience of getting back to in-person instruction after a couple of semesters during which many of us were teaching only online. It was wonderful to see student faces in the classroom again (at least what you could see of faces above everyone’s mask, that is). Students, staff, and faculty have done a great job of following public health recommendations and policies over the past few months and campus has been a safe space with regard to the pandemic. My thanks to everyone for working together to slow the spread of COVID.

This semester also saw some big changes in our personnel. Professor Roger Sunde, a member of the Nutritional Science department since 2003 retired from his faculty position in October. Roger made many groundbreaking discoveries in his research on selenium metabolism and nutrition and he had a big impact on our students as an instructor in Nutritional Sciences 510 Biochemical Principles of Human and Animal Nutrition and Nutritional Sciences 500, Undergraduate Capstone Seminar Laboratory. In addition, Senior Lecturer Pete Anderson retired from his position in August. Since 1997, Pete was the instructor in Nutritional Sciences 132 Nutrition Today, which is one of the largest enrollment courses on the UW-Madison campus. In NS 132, Pete provided quality instruction in nutrition to over 36,000 students during his almost 25-year career as a lecturer in Nutritional Sciences. We thank Roger and Pete for their tremendous service to Nutritional Sciences and UW-Madison and wish them all the best!

In this Issue:

Pete Anderson’s Retirement

From Farmer’s Market to Health Clinic

Susan Nitzke’s Art
Since 1997, Anderson has served as the sole lecturer for Nutritional Sciences 132: Nutrition Today. The course, taken by hundreds of non-science majors each semester, is an important offering for students providing them with a foundational knowledge in both science and personal health. When asked how he viewed his role in Nutritional Sciences 132, Anderson said, “I think I took nutrition to a very personal and useful level. I tried to make it very practical and applicable to daily life for non-professionals. I taught them how to evaluate information. I hope it worked.”

Being the sole instructor for a course so large and well-known across campus to undergraduate students, Anderson definitely had a very busy schedule the past 24 years. In fact, over 36,000 students have taken Nutrition Today during his time teaching the course. When asked what he did over the years at UW-Madison,
he was quick to respond by saying, “Teaching, lots of teaching.” Anderson spent his time planning and writing lectures, updating them, and talking for two hours straight. Not only did tons of talking happen in lectures, but he talked with many students during office hours, after class, and over email.

All of the talking was never grueling, working with students was Anderson’s favorite part of his position. The retired professor reminisced about the countless students who impacted him. When asked about some of his proudest moments, he mentioned multiple students telling him that his course saved their lives.

Anderson went into depth about one particular instance: “One student had just a troubled expression on her face all semester, finally telling me near the end that the course gave her the courage to come clean to her parents about her eating, and to go into treatment. She’d taken the course to gain cover for her disorder, and it turned out she blew that cover herself.” All of the talking and teaching to

so many students definitely paid off in the end. Both Anderson and his students’ lives were impacted by this class.

However, not every lecture ran so smoothly. Anderson mentioned that over the years, he experienced a fire alarm going off during an exam, a couple medical crises that involved calling 911 during lecture, lecturing with the flu, etc.

After years of teaching this large and well-known course to undergraduates, Anderson finally has a chance to relax. When asked about his retirement plans, he said, “We just bought a horse boarding farm in Hurley, WI. My high school daughters are equestrians, and we’re going to run a family farming business. I just made around 70 tons of hay.”

"I'd say it's an honor to serve the students. I had a lot of satisfaction along the way.”

Anderson’s 24 years of teaching Nutrition Today made an impact upon him and his students. The ups and downs created memories for everyone involved. After many years of teaching and hard work, he allowed students with a non-professional interest in good health to find information they can use for the rest of their lives. Anderson gave a final, closing remark about his time at UW-Madison: “I’d say it’s an honor to serve the students. I had a lot of satisfaction along the way.”
1. Tell us about your professional experiences.
I got my bachelor’s degree in biology and minor in nutritional science from Emory University. I anticipate receiving a PhD degree in nutritional science – biochemical track from the University of Wisconsin-Madison in December 2021. During my PhD training, I have been a teaching assistant and then co-instructor for three and a half years, and completed a teaching internship with the Delta Program in Research Teaching and Learning.

2. Why did you choose this profession/field?
Growing up, I had always been the “fat” kid in class. My mother, worried about me being prediabetic, sent me to a weight loss camp where I shed 50 pounds over three months. However, due to lack of basic understanding of nutrition, this seemingly positive weight loss event started a decade of weight cycling and eating disorders. I started reading everything that I could get my hands on but only became more confused about nutrition controversies and weight management. Eventually, I decided to study the basic biological mechanisms behind these nutrition controversies. I chose to be a nutritional science instructor not only because I am passionate about teaching nutrition to as many people as possible, but I also want to teach college students how to evaluate new nutrition information so they can have the tool box to foster life-long healthy habits and to their future children as well. I believe nutrition education is one of the keys to help our world recover from the obesity pandemic.
3. What do you hope to gain in this new position?
I am excited about teaching NS132 to so many students from various majors. I hope to continue to work with other colleagues and learn the best practices in teaching both in-person and online. I hope to gain additional skills to teach students how to critically evaluate information encountered in their lives. Although having previous teaching experience, I have never managed a big class like NS132 before, so I am excited to learn how to effectively teach a big class while making the classroom inclusive, equal, and safe for students from all backgrounds.

4. What goals do you hope to accomplish during your time here at UW Madison?
One of my long-term goals is to bridge the achievement gap between minority and disadvantaged students and their counterparts. Through working along with other faculty and staff in UW-Madison, I hope I can help these students navigate possible careers in STEM.

5. What are you most looking forward to as a new faculty member at UW Madison?
I look forward to re-designing NS132 to better support our First-Year-Interest-Group core course, Culture Aspects of Food and Nutrition, and to bring a newly designed NS132 online in Summer 2022. I am really excited about working with different colleagues, and about the resources on best teaching practices available to me within and outside the department of Nutritional Sciences.

6. What are Mindful Mondays” and why have you incorporated them into your teaching?
“Mindfulness Monday” is a component in my course: every Monday for 5-10 minutes, I talk about issues that my students might be struggling with, and provide tips that help them reduce stress, practice self-care, find their identities, and navigate college experience. With the pandemic and everything happening around the world, mental health issues have been on the rise and I really want to help my students to cultivate as much mental strength as possible. My class has a large percentage of freshman, and I think it is a critical period to help them understand how to deal with complex feelings and to help them smoothly transition to college life.

7. Tell us a little about your exam alternative you have started this semester.
I let my students choose from taking a final exam or a project of their choice. This is inspired by one of the professors I worked for, Dr. Eric Yen. I decided to build this component into NS132 because I want to motivate my students to dig deeper in nutrition topics that they care about most. My teaching is always student-centered, so I think it is critical to let my students learn what they think is important rather than what I think is important. This is a way to give students who cannot be measured by traditional tests a chance to showcase what they learned, and evaluate what they are good at themselves.
Students can do whatever they like as long as it (1) tells a good story, and (2) relates back to 5-10 course concepts and provides accurate information. To do this alternative project, students need to pick a topic of their interest (i.e. personalized nutrition, microbiome, etc.), and choose a format of presentation (i.e. TikTok videos, podcast, interviews, cartoons, infographics, blog articles, etc.). I provide sample project ideas, such as book reports, community nutrition projects, and literature review projects for students who want to do a project but don’t know how to start.

8. Is there anything else you would like to share?
The quality of work my students turned in just blew my mind. I have one student design a small “clinical trial” to track diet and sleep quality; another did a hand-painted comic strip on the Irish potato famine and how that affected chronic disease risk through epigenetics; two students conducted interviews with health professionals and college students to address misconceptions in nutrition; One student made TikTok videos on how to build muscle using concepts he learned in class; One student made blog articles to address food security issues in Madison and UW; Another student making videos on cooking with her Dad using Cuban spices and how she can encourage people in her community to eat more vegetables using traditional Cuban cooking technique, etc. It engages the student to think about nutrition using different mediums and different lens. The world is so interconnected and they get to demonstrate that concept within their projects. There are so many other good projects that I’m excited about!

(IRish potato famine, epigenetics and modern chronic diseases, by Mary Neville)

(The Female Athlete Triad Blog, by Kiki Risgaard)
A childhood spent around wholesome food inspires and influences this master’s student on her way to becoming a registered dietitian.

FROM FARMER’S MARKET TO HEALTH CLINIC

For some first-year college students, keeping healthy habits can be a challenge. Stress, lack of exercise and sleep, and easy access to fast food can lead to weight gain — the classic “Freshman 15.” But Naomi Moua MSx’21 never fell into that trap. She carried a health-conscious attitude into college, one that started long before she set foot on a campus.

Although her parents were not strict about nutrition, she developed her own healthy diet, primarily by reducing her junk food intake. “I stopped eating just bagels for lunch in high school, and I stopped eating doughnuts for breakfast after I went off to college,” says Moua, who is pursuing an online master’s degree in clinical nutrition at CALS.
She still makes careful choices about what she eats. But the source of her healthy habits can be traced further back, to her childhood and to the roots of her Hmong culture.

Many Hmong children live in the shadow of food insecurity, whether it’s a specter of the past or a reality of the present. Food insecurity was a common issue for most Hmong refugees living in camps in Thailand and during early U.S. resettlement. Some still face hunger today. Many members of the Hmong community supplement their food stores by gardening, and it’s an unspoken expectation for Hmong children to assist their parents with growing and selling at farmers markets.

From a young age, Moua has been helping her mother and sister manage a fresh produce stand at a farmer’s market in Green Bay. So, she grew up around healthy food. And this weekly family side gig sparked Moua’s interest in nutritional sciences — and led to her ultimate career choice.

For many Hmong people of Moua’s parents’ generation, survival defines their relationship to food. But Moua’s interest extends beyond eat-to-live to how food affects human health. A key question continues to drive Moua: What is the science behind the food we eat? And she hopes to have the opportunity to delve into this question with members of the Hmong community and other underrepresented groups — to teach them why it’s important to balance their diets, and how.

The opportunity to share knowledge with others is one of the reasons Moua aspired to become a clinical dietitian (a registered dietitian who works in a health care setting) as early as her junior year of high school.

“I had heard of Hmong doctors and nurses, but I had never heard of a Hmong clinical dietitian before then,” Moua says. “I decided I wanted to do it. Why not be the first?”

This goal steered Moua to the University of Wisconsin–Green Bay, where she earned a bachelor’s degree in human biology with an emphasis in dietetics and nutrition. Later, while pursuing her master’s program at CALS, Moua’s internship at Aspirus Riverview Hospital in central Wisconsin confirmed her passion and interest in the field. While walking rounds with doctors and nurses, she gained in-depth knowledge about human diseases and, with the guidance of a preceptor, taught patients about the relationships between their health and the foods they eat.

“We saw Naomi’s determination to achieve the RDN credential in her study of clinical nutrition in many domains — clinical, public health, and the food system — and in the time she spent in supervised experiential learning opportunities, from the school cafeteria to the ICU,” says Cassandra Vanderwall, director of the UW Health Integrated Graduate Program in Nutrition, who oversaw Moua’s internship. “Few have Naomi’s drive to serve, help, and honor, and I know this will take her far.”

Moua graduates in December 2021 with an eye toward working in a clinical setting or as a community nutrition educator or nutritionist for the federal Women, Infants, and Children program.

“I can’t wait to educate people about the different types of diseases and apply my knowledge and experiences in the real world, especially with underserved populations,” Moua says.
1. Why did you choose UW Madison?
Growing up 30 minutes from campus, I had always had my heart set on UW.

2. What is your favorite memory from attending UW Madison?
Receiving the Chancellor’s email about the school closure due to COVID-19 during a physics lecture. It was a real turning point in my life.

3. What inspired you to study nutrition/what sparked your interest in nutrition?
I doubled my body weight in high school for football (100 to 200 pounds) and developed a passion for weightlifting and sports nutrition. I used to make a 6-egg omelet with bacon, avocado, and tomato after each workout! I would also grill an entire bag of Costco chicken breasts for the week each Sunday. The summer before my freshman year at UW, I was hospitalized and diagnosed with ulcerative colitis. Since then, I’ve been fascinated with how nutrition and exercise can be used in conjunction with conventional medicine to achieve better health outcomes for people struggling with autoimmune diseases.

4. Can you describe your work/research experiences?
I started working as a CNA at the end of my senior year of high
school. I work at my hometown assisted living/memory care and I absolutely love it. With me being from a small town, I went to high school with about 1/3 of the residents’ grandkids! Despite signing a lease downtown a few months prior to the pandemic, I lived at home throughout the pandemic working 40 hours per week while attending school full-time online. In May of 2021, I got a job as a CNA at the Madison VA ICU. During normal times at UW-Madison, I conduct research through the Wisconsin State Laboratory of Hygiene. My research project focuses on alveolar macrophage response to streptococcus pneumoniae after the macrophages are exposed to particulate matter (air pollution). I also combined my passions of health, fitness, and nutrition and worked as an ACE Certified Personal Trainer for University Recreation and Wellbeing for three years.

5. What do you like to do in your free time outside of work and school?
I have tons of hobbies outside of work and school. I am an avid gym rat and lift weights 5-6 days per week. I also developed a passion for marathon running during the pandemic. I will be running the Milwaukee Lakefront Marathon this fall. When I’m not exercising, I am a hardcore hunter. My introduction to hunting was unconventional. I started with bowhunting deer when I was 18, but I have progressed on to hunting pretty much everything. In terms of nutrition, sourcing your own meat is the way to go! Outside of hunting season, I ski, fly fish, and shoot archery.

6. Anything else you would like to share?
I am currently applying to PA schools with hopes of starting right after I graduate in May of 2022. My dream in life is to work as a PA for the Alaskan Native tribes. After some time with them, I hope to settle down in a rural town, start a family, and be the town’s primary care provider.
AWARDS AND ACKNOWLEDGEMENTS

Congratulations to you all on your hard work and accomplishments!

Tierney Cushman

Congratulations to Tierney Cushman! Tierney, an undergraduate Nutritional Sciences major, received a 2021 Returning Adult Student Scholarship, called the Single Parent Undergraduate Scholarship.

Raven Hall

Congratulations to Raven Hall! Raven, one of our Nutritional Sciences students, received the UW System Regents Opportunity Scholarship.
Tara McCloskey

Congratulations to Tara McCloskey! Tara, an undergraduate Nutritional Sciences major, received three 2021 Returning Adult Student Scholarships: The Crankstart Reentry Scholarship, Bernard Osher Reentry Scholarship, and the Single Parent Undergraduate Scholarship.

Alicia Monson

Congratulations to Alicia Monson for finishing 3rd in the 10k run at the 2020 U.S. Olympic Track and Field Trials. Finishing in 31:18.55, Alison became an Olympian for the first time! Monson graduated in Fall 2020 with a degree in Nutrition and Dietetics.

Rashaun Williams

Congratulations to Rashaun Williams! Rashuan, an IGPNS graduate student, won the 2021-2022 Porter Physiology Development Fellowship. This is a competitive external fellowship and we are happy to hear of his recognition.
NEW FACULTY PROFILE

JOE PIERRE

JOE PIERRE STUDIES DIET, GUT PHYSIOLOGY, AND THE MICROBIOME IN HEALTH AND DISEASE

Joe Pierre joined the UW–Madison faculty in October 2021 as an assistant professor in the Department on Nutritional Sciences. Funding for this nutrition-focused position comes from the Dairy Innovation Hub, which has supported 11 faculty positions so far at UW–Madison, UW–Platteville and UW–River Falls.

What is your hometown? Where did you grow up?
I grew up in Green Bay and Door County, Wisconsin, a little over 2 hours northeast of Madison.

What is your educational/professional background, including your previous position?
I attended UW–Madison as an undergraduate (BS in natural science) where I was a student athlete in track and cross country from 2005-2008. I then completed a Ph.D. in nutritional sciences through the IGPNS program at UW. Following graduation, my postdoctoral fellowship training was in gastroenterology, hepatology, and nutrition at the University of
Chicago. Prior to joining the UW faculty, I was most recently an assistant professor of pediatrics, microbiology, immunology, and biochemistry at the University of Tennessee Health Science Center.

**How did you get into your field of research?**
The gastrointestinal tract serves as the largest “external” surface of the body and is tasked with digesting and absorbing nutrients, mediating cohabitation with trillions of microorganisms, and acting at the largest endocrine and immune organ. As I learned more about the many important roles the gut plays in human health, I became more fascinated by how diet and resident microbial communities fundamentally shape metabolic and immune responses in the gut and throughout the body. My fellowship training was focused on the tools and concepts for studying the gut microbiome and host metabolites. Putting all these experiences together, it was a natural next step to bring these experiences and interests back to the field of nutritional sciences.

**What are the main goals of your current research program?**
My research program has been centered around understanding the roles of diet, gut physiology, and the microbiome in health and disease. We have existing NIH funding examining the role of diet and bariatric surgery on breast cancer outcomes, the role of the microbiome/mycobiome in inflammatory bowel disease, and how extraintestinal microbial communities (in circulation) shape cardiovascular events. At UW, my program will continue to utilize diverse experimental tools (bariatric surgery, parenteral nutrition, gnotobiotics, microbial sequencing, and enteroids) to gain deeper insights into nutritionally relevant areas — emphasizing dairy components — in the context of disease treatment, prevention and optimizing human health.

**What attracted you to UW–Madison?**
UW–Madison is a research powerhouse with thousands of talented faculty colleagues, laboratory resources, core facilities, along with thoughtful and hardworking students and trainees to interact with. If there is a scientific hypothesis worth testing, you can successfully pursue it at the UW.

**What was your first visit to campus like?**
I believe my first ‘visit’ to campus was as a child (my brother was an engineering student), but I remember touring campus as a high school track recruit with then head coach, Ed Nuttycombe. The impression and beauty of this campus never gets old.
What’s one thing you hope students who take a class with you will come away with?
I hope my students are inspired by the materials and concepts and go on to pursue lifelong curiosity outside of the classroom that enriches their lives and professional careers.

Do you share your expertise and experiences with the public through social media? If so, which channels do you use?
I am an infrequent user of social media but maintain a Twitter and LinkedIn account.

Do you feel your work relates in any way to the Wisconsin Idea? If so, please describe how.
Absolutely. The pursuit of basic and translational research knowledge — especially in metabolism, nutrition, and health — benefits the residents of Wisconsin and beyond. More specifically, a key emphasis of my program is gaining deeper insights into the use of dairy components and products in human health and nutrition. Milk is a fundamentally important source of nutrition in mammalian biology. Dairy products contain complete protein, hundreds of bioactive peptides and enzymes, and unique lipids that have been key assets to human agriculture and success for millennia. Beyond human health, dairy is economically important to Wisconsin and many populations around the globe.

What’s something interesting about your area of expertise you can share that will make us sound smarter at parties?
It may sound cliché, but we really are a product of what we eat. Beyond energy, our diets begin an enormously complex cascade of metabolites, microbial adaptation and selection, and host cell and organ system responses that are fascinating and interconnected in many ways that we’re still trying to understand. Appreciating the catalyzing role of diet synergizes with the biochemical, genetic, environmental, lifestyle and microbiological academic pursuits in understanding human biology.

What are your hobbies and other interests?
As a father of several young kids, I spend a lot of time at home, with the occasional camping trip or golf outing.

Nancy Ebersole Johnson, age 95, passed away peacefully on May 18, 2021, in Honolulu, Hawaii. She was born to Paul and Mildred Ebersole on Dec. 12, 1925, in South Dakota and was raised in Fort Dodge, Iowa. Nancy is survived by her sons, Christopher (Edie), Jeffrey (Claudia) and Brian (Kate); grandchildren, Katherine, Kevin, Eric, Kelsey, Whitney, Megan, and Molly; and her brother, Robert (Doris). She has four great-grandchildren. Her husband, Robert Lewis Johnson, preceded her in death in 2009.

Nancy received a B.S. degree (chemistry) from Iowa State in 1947, followed by a master's degree (food and nutrition) in 1949. In 1969 she received a Ph.D. from the Department of Nutritional Science at University of Wisconsin-Madison and subsequently served on the faculty in the department for over 20 years, including a joint appointment with University of Wisconsin-Extension. In 1986 she was asked to become the chairperson of the Department of Food and Nutrition at the University of Hawaii-Manoa, where she served until retirement in 1996. In 2000 she was awarded emeritus status at UW.

Nancy relished the academic environment and years spent with students and faculty. She traveled extensively throughout the world and enjoyed meeting colleagues with a focus on international nutritional problems. She maintained a high level of intellectual curiosity throughout her life and was an avid reader on many subjects. She participated in athletics during her earlier years. Her favorite sport was golf. She lived in Hawaii for over 30 years and traveled back and forth to Wisconsin frequently. She appreciated the beauty of Hawaii, taking frequent walks and observing the sunsets. She enjoyed music, the arts and fine dining, especially desserts (her favorites were a Wisconsin turtle sundae and Hawaiian lava cake).
SUSAN NITZKE’S ART

Susan’s professional education included a B.S. in Foods and M.S. and Ph.D. degrees in Nutritional Sciences from the University of Wisconsin-Madison. She was a Professor Emerita from the Nutritional Sciences Department at the University of Wisconsin-Madison and UW-Extension. Her areas of expertise were community nutrition and nutrition education.

Susan also was a member of the Madison Watercolor Society, the Wisconsin Regional Artists Association, and the Transparent Watercolor Society of America.

ABOUT THE ARTIST

“As an artist, I am fascinated by watercolor pigments as they interact with water to form interesting, and sometimes unpredictable, shapes and patterns on an otherwise uninteresting piece of white paper. Whether abstract, representational, or in-between, the images that I paint are inspired by the beauty that I see in nature.”

To learn more about Susan and her art, go to https://www.suenitzkeart.com/
Total daily energy expenditure (“total expenditure”) reflects daily energy needs and is a critical variable in human health and physiology, but its trajectory over the life course is poorly studied. We analyzed a large, diverse database of total expenditure measured by the doubly labeled water method for males and females aged 8 days to 95 years. Total expenditure increased with fat-free mass in a power-law manner, with four distinct life stages. Fat-free mass-adjusted expenditure accelerates rapidly in neonates to ~50% above adult values at ~1 year; declines slowly to adult levels by ~20 years; remains stable in adulthood (20 to 60 years), even during pregnancy; then declines in older adults. These changes shed light on human development and aging and should help shape nutrition and health strategies across the life span.

https://www.science.org/doi/10.1126/science.abe5017
All of life's essential tasks, from development and reproduction to maintenance and movement, require energy. Total daily energy expenditure (total expenditure; megajoules per day) is thus central to understanding both daily nutritional requirements and the body’s investment among activities. Yet, we know surprisingly little about total expenditure in humans or how it changes over the life span. Most large (n > 1000 subjects) analyses of human energy expenditure have been limited to basal expenditure—the metabolic rate at rest (1), which accounts for only a portion (usually ~50 to 70%) of total expenditure—or have estimated total expenditure from basal expenditure and daily physical activity (2–5). Doubly labeled water studies provide measurements of total expenditure in free-living subjects but have been limited in sample size (n < 600 subjects), geographic and socio-economic diversity, and/or age (6–9).

Body composition, size, and physical activity change over the life course, often in concert, making it difficult to parse the determinants of energy expenditure. Total and basal expenditures increase with age as children grow and mature (10, 11), but the relative effects of increasing physical activity and age-related changes in tissue-specific metabolic rates are unclear (12–16). Similarly, the decline in total expenditure beginning in older adults corresponds with declines in fat-free mass and physical activity but may also reflect age-related reductions in organ metabolism (9, 17–19).

We investigated the effects of age, body composition, and sex on total expenditure using a large (n = 6421 subjects; 64% female), diverse (n = 29 countries) database of doubly labeled water measurements for subjects aged 8 days to 95 years (20), calculating total expenditure from isotopic measurements by using a single, validated equation for all subjects (21). Basal expenditure, measured with indirect calorimetry, was available for n = 2008 subjects, and we augmented the dataset with additional published measures of basal expenditure in neonates and doubly labeled water–measured total expenditure in pregnant and postpartum women (supplementary materials, materials and methods, and table S1).

We found that both total and basal expenditure increased with fat-free mass in a power-law manner (Fig. 1, figs. S1 and S2, and table S1), requiring us to adjust for body size to isolate potential effects of age, sex, and other factors. Because of the power-law relation with size, the ratio of energy expenditure/mass does not adequately control for body size because the ratio trends lower for larger individuals (fig. S1). Instead, we used regression analysis to control for body size (22). We used a general linear model with log-transformed values of energy expenditure (total or basal), fat-free mass, and fat mass in adults 20 to 60 years (table S2) to calculate residual expenditures for each subject. We converted these residuals to “adjusted” expenditures for clarity in discussing age-related changes: 100% indicates an expenditure that matches the expected value given the subject’s fat-free mass and fat mass, 120% indicates an expenditure 20% above expected, and so on. Using this approach, we also calculated the portion of adjusted total expenditure attributed to basal expenditure (Fig. 2D and materials and methods). Segmented regression analysis (materials and...
Figure 1

Total energy expenditure (TEE) through the human life course. (A) TEE increases with fat-free mass (FFM) in a power-law manner, but age groups cluster about the trend line differently. The black line indicates $\text{TEE} = 0.677\text{FFM}^{0.708}$. Coefficient of determination ($R^2$) = 0.83; $P < 0.0001$ (table S2). (B) Total expenditure rises in childhood, is stable through adulthood, and declines in older adults. Means ± SD for age-sex cohorts are shown. (C) Age-sex cohort means show a distinct progression of total expenditure and fat-free mass over the life course. (D) Neonates, juveniles, and adults exhibit distinct relationships between fat-free mass and expenditure. The dashed line, extrapolated from the regression for adults, approximates the regression used to calculate adjusted total expenditure.
methods) revealed four distinct phases of adjusted total and basal expenditure over the life span.

The first phase is of neonates, up to 1 year of age. Neonates in the first month of life had size-adjusted energy expenditures similar to that of adults, with adjusted total expenditure of 99.0 ± 17.2% (n = 35 subjects) and adjusted basal expenditure of 78.1 ± 15.0% (n = 34 subjects) (Fig. 2). Both measures increased rapidly in the first year. In segmented regression analysis, adjusted total expenditure rose 84.7 ± 7.2% per year from birth to a break point at 0.7 years of age [95% confidence interval (CI): 0.6, 0.8]; a similar rise and break point were evident in adjusted basal expenditure (table S4). For subjects between 9 and 15 months of age, adjusted total and basal expenditures were nearly ~50% elevated compared with that of adults (Fig. 2).

The second phase is of juveniles, 1 to 20 years of age. Total and basal expenditure continued to increase with age throughout childhood and adolescence along with fat-free mass (Fig. 1), but size-adjusted expenditures steadily declined. Adjusted total expenditure declined at a rate of −2.8 ± 0.1% per year from 147.8 ± 22.6% for subjects 1 to 2 years of age to 102.7 ± 18.1% for subjects 20 to 25 years of age (tables S2 and S4). Segmented regression analysis identified a break point in adjusted total expenditure at 20.5 years (95% CI: 19.8, 21.2), after which it plateaued at adult levels (Fig. 2); a similar decline and break point were evident in adjusted basal expenditure (Fig. 2 and table S4). No pubertal increases in adjusted total or basal expenditure were evident among subjects 10 to 15 years of age (Fig. 2 and table S3). In multivariate regression for subjects 1 to 20 years of age, males had a higher total expenditure and adjusted total expenditure (tables S2 and S3), but sex had no detectable effect on the rate of decline in adjusted total expenditure with age (sex:age interaction, P = 0.30).

The third phase is adulthood, from 20 to 60 years of age. Total and basal expenditure and fat-free mass were all stable from ages 20 to 60 years (Figs. 1 and 2 and tables S1 and S2). Sex had no effect on total expenditure in multivariate models with fat-free mass and fat mass, nor in analyses of adjusted total expenditure (tables S2 and S4). Adjusted total and basal expenditures were stable even during pregnancy; the elevation in unadjusted expenditures matched those expected from the gain in mothers’ fat-free mass and fat mass (Fig. 2C). Segmented regression analysis identified a break point at 63.0 years of age (95% CI: 60.1, 65.9), after which adjusted total expenditure begins to decline. This break point was somewhat earlier for adjusted basal expenditure (46.5, 95% CI: 40.6, 52.4), but the relatively small number of basal measures for 45 to 65 years of age (Fig. 2) reduces our precision in determining this break point.

The fourth phase is of older adults, >60 years of age. At ~60 years of age, total and basal expenditure begin to decline, along with fat-free mass and fat mass (Fig. 1, fig. S3, and table S1). Declines in expenditure are not only a function of reduced fat-free mass and fat mass, however. Adjusted total expenditure declined by −0.7 ± 0.1% per year, and adjusted basal expenditure fell at a similar rate (Fig. 2, fig. S3, supplementary text S1, and table S4). For subjects 90+ years of age, adjusted total expenditure was ~26% below that of middle-aged adults.

https://www.science.org/doi/10.1126/science.abe5017
**Figure 2**

Fat-free mass- and fat mass-adjusted expenditures over the life course. Individual subjects and age-sex cohort mean ± SD are shown. For both (A) total expenditure (adjusted TEE) and (B) basal expenditure (adjusted BEE), adjusted expenditures begin near adult levels (~100%) but quickly climb to ~150% in the first year. Adjusted expenditures decline to adult levels at ~20 years of age then decline again in older adults. Basal expenditures for infants and children not in the DLW Database are shown in gray. (C) Pregnant mothers exhibit adjusted total and basal expenditures similar to those of nonreproducing adults (Pre, before pregnancy; Post, 27 weeks postpartum). (D) Segmented regression analysis of adjusted total (red) and adjusted basal expenditure (black) (calculated as a portion of total, Adj. BEETEE) indicates a peak at ~1 year of age, adult levels at ~20 years of age, and decline at ~60 years of age.
Our analyses provide empirical measures and predictive equations for total and basal expenditure from infancy to old age (tables S1 and S2) and bring to light major metabolic changes across the life course. To begin, we can infer fetal metabolic rates from maternal measures during pregnancy: If body size–adjusted expenditures were elevated in the fetus, then adjusted expenditures for pregnant mothers—particularly late in pregnancy, when the fetus accounts for a substantial portion of a mother’s weight—would be likewise elevated. Instead, the stability of adjusted total and basal expenditures at ~100% during pregnancy (Fig. 2B) indicates that the growing fetus maintains a fat-free mass– and fat mass–adjusted metabolic rate similar to that of adults, which is consistent with adjusted expenditures of adjusted values, then accelerate rapidly over the first year. This early period of metabolic acceleration corresponds to a critical period in early development in which growth often falters in nutritionally stressed populations (23). Increasing energy demands could be a contributing factor.

After rapid acceleration in total and basal expenditure during the first year, adjusted expenditures progressively decline thereafter, reaching adult levels at ~20 years of age. Elevated adjusted expenditures in these life stages may reflect the metabolic demands of growth and development. Adult expenditures, adjusted for body size and composition, are remarkably stable, even during pregnancy and postpartum. Declining metabolic rates in older adults could increase the risk of weight gain. However, neither fat mass nor percentage increased in this period (fig. S3), which is consistent with the hypothesis that energy intake is coupled to expenditure (24). Following previous studies (15, 16, 19, 25, 26), we calculated the effect of organ size on basal expenditure over the life span (materials and methods). Organs with a high tissue-specific metabolic rate, particularly the brain and liver, account for a greater proportion of fat-free mass in young individuals. Thus, organ-based basal expenditure, estimated from organ size and tissue-specific metabolic rate, follows a power-law relationship with fat-free mass that is roughly consistent with observed basal expenditures (materials and methods, and fig. S6). Still, observed basal expenditure exceeded organ-based estimates by ~30% in early life (1 to 20 years of age) and was ~20% lower than organ-based estimates in subjects over 60 years of age (fig. S6), which is consistent with studies indicating that tissue-specific metabolic rates are elevated in juveniles (15, 16) and reduced in older adults (19, 25, 26).

We investigated the contributions of daily physical activity and changes in tissue-specific metabolic rate to total and basal expenditure using a simple model with two components: activity and basal expenditure (Fig. 3 and materials and methods). Activity expenditure was modeled as a function of physical activity and body mass, assuming that activity costs are proportional to weight, and could either remain constant over the life span or follow the trajectory of daily physical activity measured with accelerometry, peaking at 5 to 10 years of age and declining thereafter (Fig. 3) (12, 17, 18). Similarly, basal expenditure was modeled as a power function of fat-free mass (consistent with organ-based basal expenditure estimates) (materials and methods) multiplied by a “tissue-specific
Figure 3

Modeling the contribution of physical activity and tissue-specific metabolism to daily expenditures. (A) Observed total expenditure (TEE; red), basal expenditure (BEE; black), and activity expenditure (AEE; gray) (table S1) show age-related variation with respect to fat-free mass (Fig. 1C) that is also evident in adjusted values (Fig. 2D and table S3). (B) These age effects do not emerge in models that assume constant physical activity (PA; green) and tissue-specific metabolic rate (TM; black) across the life course. (C) When physical activity and tissue-specific metabolism follow the life course trajectories evident from accelerometry and adjusted basal expenditure, respectively, model output is similar to observed expenditures.
metabolism” term, which could either remain constant at adult levels across the life span or follow the trajectory observed in adjusted basal expenditure (Fig. 2). For each scenario, total expenditure was modeled as the sum of activity and basal expenditure (materials and methods).

Models that hold physical activity or tissue-specific metabolic rates constant over the life span do not reproduce the observed patterns of age-related change in absolute or adjusted measures of total or basal expenditure (Fig. 3). Only when age-related changes in physical activity and tissue-specific metabolism are included does model output match observed expenditures, indicating that variation in both physical activity and tissue-specific metabolism contribute to total expenditure and its components across the life span. Elevated tissue-specific metabolism in early life may be related to growth or development (15, 16). Conversely, reduced expenditures in later life may reflect a decline in organ-level metabolism (25–27).

Metabolic models of life history commonly assume continuity in tissue-specific metabolism over the life course, with metabolic rates increasing in a stable, power-law manner (28, 29). Measures of humans here challenge this view, with deviations from the power-law relationships for total and basal expenditure in childhood and old age (Figs. 1 and 2). These changes present a potential target for investigating the kinetics of disease, drug activity, and healing, processes that are intimately related to metabolic rate. Further, interindividual variation in expenditure is considerable even when controlling for fat-free mass, fat mass, sex, and age (Figs. 1 and 2 and table S2).

Elucidating the processes underlying metabolic changes across the life course and variation among individuals may help reveal the roles of metabolic variation in health and disease.

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Supplementary Materials

science.sciencemag.org/content/373/6556/808/suppl/DC1 Materials and Methods Figs. S1 to S10 Tables S1 to S4 IAEA DLW Database Consortium Collaborators List References (30–54) MDAR Reproducibility Checklist View/request a protocol for this paper from Bio-protocol. 27 August 2020; accepted 21 June 2021 10.1126/science.abe5017
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