Sex-biased investment: Measuring energy expenditure in baboon mothers

Christine Adjangba[1], Laurence Gesquiere[1], Susan Alberts[1]

[1]Duke University

Female reproduction is energetically costly, especially among mammals. Females need extra energy for fetal and maternal tissue development during gestation, and during postpartum amenorrhea (PPA) for milk production and infant carrying. Sex-biased investment can be expected in species where one sex has greater variation in reproductive success compared to the other sex. Across several primate species, producing sons is considered to be costlier than producing daughters. To date, few studies have directly assessed the energy expenditure of mothers raising sons versus daughters. Using measurements of fecal triiodothyronine metabolites (mT3) and fecal glucocorticoid (fGC) concentrations as markers of energy balance, we tested the hypothesis that maternal hormones reflected the higher energetic costs associated with producing sons than daughters in wild female baboons. We predicted that gestating and lactating mothers raising sons would have lower mT3 and higher fGC concentrations than mothers raising daughters. We investigated potential sources of variance in mT3 and fGC during gestation and PPA using an information theoretic approach. Our hypothesis was not supported by our results – mT3 and fGC levels did not differ by infant sex during gestation or PPA across the majority of our models. However, contrary to our expectations, we found that the highest-ranking (alpha) females rearing daughters had significantly lower mT3 during PPA compared to alpha females rearing sons. Our findings suggest that female baboons generally expend the same amount of energy into their offspring regardless of sex, but that alpha females expend greater energy when producing daughters than sons.

Ecological and energetic correlates of cultural behavior in wild western Ugandan chimpanzees (*Pan troglodytes schweinfurthii*)

Elizabeth F. Ballare[1,2], Kelly R. Mannion[1], Erin R. Vogel[2], Thibaud Gruber[1]

[1]Centre Interfacultaire en Sciences Affectives (CISA), University of Geneva, Switzerland
[2]Department of Anthropology, Rutgers, The State University of New Jersey, USA

The debate on chimpanzee culture has more recently focused on ecological explanations, particularly in relation to tool-assisted cultural traits. As such, the opportunity or necessity hypotheses have become integral to the discussion and attempt to link ecological and cultural variation as not mutually exclusive when explaining chimpanzee cultural behavior. Nevertheless, connecting ecology and foraging behavior remains incomplete if the effect of ecological variation on the individuals displaying cultural traits is not addressed. A first step in this direction is to explore how connect ecological variation influences energetics and physiology. In this project, we will explore such connections in a semi-habituated chimpanzee community in Bugoma Forest Reserve, western Uganda. Urine samples are now being non-invasively collected across the dry and rainy seasons to examine the relationship between dietary trends, energetics, and health using urea, creatinine, ketone bodies, C-peptide of insulin, cortisol, and T3 as proxies of energetics status and health. Here we will present preliminary data on ecological variation in the Bugoma forest area, and present hypotheses related to tool use behavior in the forest. By combining these data with natural behavioral and experimental observations, the proposed research aims to determine the drivers of potential cultural behavior in the Bugoma chimpanzees, and more generally connect energetics with the expression of cultural behavior in the wild.

Modeling the Energetic Cost of Stress Adaptation in Human Cells

Natalia Bobba-Alves[1], Gabriel Sturm[1], Jue Lin[2], Albert Higgins-Chen[3], Morgan Levine[4], Steve Horvath[4], Michio Hirano[1], Elissa Epel[2], Martin Picard[1]

[1]Columbia University
[2]UCSF
[3]Yale
[4]Altos Labs

Stress triggers energy-dependent, anticipatory responses that promote survival, a phenomenon termed allostasis. However, the chronic activation of allostatic responses can result in allostatic load (AL), a maladaptive state of physiological dysregulation that compromises longevity. Epidemiological studies show that allostatic load predicts physical and cognitive decline, as well as earlier mortality; yet the energetic manifestations of allostatic load at the cellular level remain unclear. To define the energetic cost and the maladaptive effects of prolonged cellular allostatic load, we developed a longitudinal in vitro model of chronic glucocorticoid stress in primary human fibroblasts. Results replicated across multiple donors demonstrated that chronic glucocorticoid stress robustly increased cellular energy expenditure by 62% ($p<0.001$). Using extracellular flux analysis to simultaneously monitor mitochondrial oxygen consumption and indirectly monitor glycolysis, we find that this hypermetabolic state relies on a bioenergetic shift away from glycolysis and towards mitochondrial oxidative phosphorylation. This shift was supported by an upregulation of mitochondrial biogenesis and increased cellular mitochondrial DNA content. As in humans where chronic stress accelerates biological aging, chronic glucocorticoid stress increased the rate of aging based on two independent measures: DNA methylation clocks and telomere shortening. In validation studies, metabolic perturbations other than glucocorticoids also altered energy expenditure, accelerated telomere shortening, and predictably reduced cellular lifespan. Together, these results i) quantify the energetic cost of stress at the cellular level, ii) define metabolic rewiring un cells under allostatic load, and iii) suggests a mechanism for the transduction of chronic stress into accelerated cellular aging to be examined in humans.

Old male chimpanzees decrease energetically expensive behaviors and maintain energy balance at Ngogo, Kibale National Park, Uganda

Benjamin Finkel[1,2], Sharifah Namaganda[2,3]

[1]University of Michigan, Department of Anthropology
[2]Ngogo Chimpanzee Project
[3]Makerere University

Physical performance is expected to decline with age, which can impact both nutritional acquisition and in turn energetic condition. However, there is scant evidence that old non-human primates suffer from frailty or energetic stress until they are acutely near death. We investigated the effect of socioecological factors on the energetic status of adult male chimpanzees, a particularly long-lived species. Here, we analyze urinary c-peptide (n=722), a marker of energetic condition, and behavioral data collected from 20 adult males (n=1385 observation hours) from two communities at Ngogo in Kibale National Park over 12 months. We found that energetic status was positively associated with the proportion of ripe drupe fruits in the diet, but not age or rank (Elo rating). In contrast, travel time and climbing distance decrease with age, while foraging time increases. We also found that social display frequency and distance decreased, even when controlling for rank. These results suggest that in a population with access to abundant, high-quality foods, adult males maintain their energetic status despite deteriorating physical performance. While rank declines in old age, this decrease does not explain reductions in costly social behaviors like displays. Although adult male chimpanzees are known to maintain body condition until late in life, these findings suggest that they may confront energetic tradeoffs due to deteriorating physical performance.

Energy Compensation and Metabolic Adaptation in Response to Aerobic Exercise Training

Emily W. Flanagan[1], Herman Pontzer[2], Corby K. Martin[3], Leanne M. Redman[1]

[1]Reproductive Endocrinology and Women's Health Laboratory, Pennington Biomedical Research Center
[2]Evolutionary Anthropology & Global Health Institute, Duke University
[3]

Background: Exercise increases total daily energy expenditure (TDEE) and is therefore commonly prescribed for weight loss. Yet, exercise interventions often result in less weight loss than expected. While concomitant and opposing increases in energy intake often contribute to diminished weight loss, another underpinning theory posits that increased TDEE in response to exercise is often less than predicted from the actual energy cost of the prescribed exercise. The mechanisms behind this phenomenon, coined "energy compensation", are poorly understood. More understood is metabolic adaptation, a physiological response to perturbations in weight-induced changes in energy expenditure. Adaptations occur when metabolic rate changes to a greater (in the context of weight gain) or lesser (in the context of weight loss) extent than would be expected by the changes of fat-free mass and fat mass. It is plausible that metabolic adaptation is implicated in energy compensation in response to prolonged exercise, to preserve body mass and conserve energy for other important physiological functions. The aim of this analysis was to identify if individuals who exhibit energy compensation in response to an aerobic exercise intervention also have metabolic adaptations across various domains of energy expenditure (EE) including: 1) 24-hour EE, 2) SleepEE, and 3) resting EE (REE).

Methods: This was a secondary analysis of individuals enrolled in the Examination of Mechanisms of Exercise-induced Weight Compensation (E-MECHANIC) study. Sedentary individuals with obesity were randomized to a 24-week aerobic exercise intervention to expend either 8 kcal per kilogram per week (8KKW) or 20 kcal per kilogram per week (20 KKW). Energy expenditure was assessed using doubly labeled water (DLW) and 24-hour metabolic chamber at rest and during the last 2 weeks of the 24-week intervention. Metabolic Adaptation was calculated for 24-hourEE, SleepEE, and REE. Energy compensation was calculated as the difference between free-living TDEE at week 24 and predicted TDEE, as calculated by TDEE at baseline and exercise energy expenditure per week.

Results: Of the 29 participants who completed the exercise intervention and metabolic chamber stays, 14 showed exercise compensation of greater than 5% (-308±158 kcals / day less than predicted compared to 94±124 kcals / day more than predicted in those who did not compensate, p<0.001). There was no difference in sex, age, BMI, or exercise intensity between those who compensated and those who did not. Exercise compensation was significantly associated with baseline TDEE (r=-0.50, p=0.006). There were no differences in metabolic adaptations for 24hrEE, SleepEE, or REE between those who exhibited exercise compensation and those who did not.

Conclusion: Energy compensation occurs independent of metabolic adaptations in other components of EE and may equate to physiological efficiency with prolonged aerobic training.

The energetic consequences of living in a highly seasonal environment

Laurence Gesquiere[1], Catherine Markham[2], Georgia Young[1], Christine Adjangba[1], Susan C. Alberts[1]

[1]Duke University
[2]Stony Brook University

Understanding how environmental factors affect individuals' energetic balance and consequently their reproduction remains understudied in wild animals, in large part because accurately and repeatedly measuring energetic metabolism in the wild is challenging. However, recent advances in the non-invasive measurement of fecal thyroid hormones as markers of energetic balance is providing such an opportunity. In this study, measuring fecal metabolites of triiodothyronine (mT3) in the well-studied Amboseli baboons, we sought to understand how female savannah baboons living in the harsh Amboseli ecosystem in southern Kenya have escaped strict reproductive seasonality, allowing them to conceive and give birth in all months of the year. Specifically, we assessed how females' activity budget, diet, and mT3 concentrations changed across seasons and across years. We then tested which of several environmental variables (season, rainfall and temperature) and behavioral variables (female activity budget and diet) predicted mT3 concentrations. Finally, we determined if two important reproductive events, onset of cycling and conception, were preceded by changes in female mT3 concentrations. We found that female baboons' energetic balance varied markedly across seasons and across years in relation to environmental conditions. We also documented pronounced behavioral responses to environmental variation, which in turn predicted mT3 concentrations, suggesting that baboons attempted to mitigate environmental challenges by changing their behavior. In addition, we observed an increase in mT3 concentrations in the weeks prior to the onset of menarche and prior to the resumption of cycling after lactational amenorrhea, indicating that energetic balance affected a female's reproductive status.

The energetic costs of being the alpha male in wild baboons

Laurence Gesquiere[1], Christine Adjangba[1], Georgia Young[1], Sophie Brenner[1], Clara Brandon[1], Susan Alberts[1]

[1]Duke University

In captive primates, low social dominance rank has commonly been associated with elevated glucocorticoid (GC) concentrations as subordinates lack predictability and control in their daily life. In wild populations, however, high GC concentrations have been also reported in high-ranking animals. This is a puzzling finding as high status is normally associated with low psychological stress. Several studies have suggested that elevated GCs in dominant animals are the consequence of the high energetic demands associated with high rank such as agonistic and sexual activities. As GCs are elevated in response to both energetic and psychological stressors, it is difficult to differentiate between these two stressors by measuring GCs. Recent advances in the non-invasive measurement of fecal thyroid hormones as an important marker of energy metabolism is providing a novel opportunity to examine the cost of dominance rank in the wild. Here, using fecal determination of glucocorticoid (fGC) and triiodothyronine (mT3) metabolites in male Amboseli baboons, we assessed how fGC and mT3 concentrations vary as a function of dominance rank and hierarchy stability controlling for environmental factors, age and group size. Alpha males had higher fGC and lower mT3 than other males, and the effect on mT3 was amplified when the hierarchy was unstable. In contrast, low ranking males had higher mT3 than high ranking males despite comparable fGC. Taken together, these results suggest that being the alpha male is energetically costly especially when the hierarchy is unstable, but that being a subordinate while less energetically costly is more psychologically stressful.

Infant Carrying Technology and Maternal Foraging Efficiency

Alexandra Greenwald[1], Gregory Burns[1], Carly Whelan[2], Abby Baka[1], Ja'net Baide[1], Hayley Kievman[1]

[1]University of Utah
[2]CSU Chico

Women in western North America developed and employed a unique technology relative to hunter-gatherers worldwide. Rather than transporting infants in slings during foraging and processing, mothers relied on basketry cradles that permitted them to efficiently carry the infant to a foraging site and safely prop the infant nearby while working. This paper presents results of an experiment tracking foraging returns and metabolic expenditures of three treatment groups (control, cradle-carried infant, and sling-carried infant) engaged in acorn gathering to test the hypothesis that transporting infants in cradles increases maternal foraging efficiency and decreases maternal metabolic expenditures relative to sling-transport.

The energetics of uniquely human subsistence strategies

Thomas S. Kraft[1,2],*, Vivek V. Venkataraman[3,4], Ian J. Wallace[5], Alyssa N. Crittenden[6], Nicholas B. Holowka[7], Jonathan Stieglitz[3], Jacob Harris[8,9], David A. Raichlen[10], Brian Wood[2,8], Michael Gurven[1], Herman Pontzer[11,12]

[1]Department of Anthropology, University of California, Santa Barbara, Santa Barbara, USA
[2]Department of Human Behavior, Ecology, and Culture, Max Planck Institute for Evolutionary Anthropology, Leipzig, Germany
[3]Institute for Advanced Study in Toulouse, Toulouse, France
[4]Department of Anthropology and Archaeology, University of Calgary, Calgary, CA
[5]Department of Anthropology, University of New Mexico, Albuquerque, USA
[6]Department of Anthropology, University of Nevada, Las Vegas, Las Vegas, USA
[7]Department of Anthropology, University at Buffalo, Buffalo, USA
[8]Department of Anthropology, University of California, Los Angeles, Los Angeles, USA
[9]Institute of Human Origins, School of Human Evolution and Social Change, Arizona State University, Tempe, USA
[10]Human and Evolutionary Biology Section, Department of Biological Sciences, University of Southern California, Los Angeles, USA
[11]Department of Evolutionary Anthropology, Duke University, Durham, USA
[12]Duke Global Health Institute, Duke University, Durham, USA

The suite of derived human traits, including enlarged brains, elevated fertility rates, and long developmental periods and lifespans, imposes extraordinarily high energetic costs compared to other great apes. How do human subsistence strategies accommodate our expanded energy budgets? Using a combination of doubly-labeled water, respirometry, long-term foraging observation, and time allocation data,, we show that compared to other great apes, human hunter-gatherers and subsistence farmers spend more energy but less time on subsistence, acquire substantially more energy per hour, and achieve similar energy efficiencies. These findings revise our understanding of human energetic evolution by indicating that humans afford expanded energy budgets by increasing rates of energy acquisition, not through energy-saving adaptations such as economical bipedalism or sophisticated tool use that decrease subsistence costs and improve the energetic efficiency of subsistence. We argue that the time saved by human subsistence strategies provides more leisure time for social interaction and social learning in central-place locations and would have been critical for cumulative cultural evolution.

The metabolic allostatic response to stress (MARS) hypothesis: patterns from studies of metabolic responses to cold stress and other stressors

Stephanie B. Levy[1,2]

[1]Department of Anthropology, CUNY Hunter College, New York, NY
[2]New York Consortium in Evolutionary Primatology, New York, NY

It has been hypothesized that cooperative breeding is central to the evolution of the human life history, but disentangling the relationships between the energetic costs of the different forms of care provided by many care givers is challenging. Biparental care offers a simplified form of cooperative breeding since maternal care is only modified by the care of one individual: the father. I will investigate the relative contributions of male and female titi monkey parents (*Plecturocebus cupreus*) to the care of their infants. I hypothesize that males do not compensate for maternal energy invested in their offspring during gestation, a time when they cannot provide direct care to the infant, but do compensate for maternal investment following birth, when they can. Therefore, I predict that following the birth of the infant both parents' total energy expenditure (TEE) will be similar until the end of infant care. I will test this prediction using a combination of behavioral data, and energetic data derived from doubly labeled water and accelerometers, collected from captive titi monkeys at the California Primate Research Center in Davis, CA. Throughout the entire period of infant care, I will collect behavioral data from 10 reproductive pairs, activity data from 10 reproductive and 10 nonreproductive pairs, and energetic data from 10 reproductive and 4 nonreproductive pairs. This design allows me to make inferences about the energetic investment parents make during infant care since measures of TEE will be in the context of behavior and activity, and comparable to a nonreproductive baseline.

Energetics in Pathogen Variant Environments in India

Anup Malani[1], Stacy Rosenbaum[2]

[1]University of Chicago
[2]University of Michigan

Roughly one out of every eight people in the world lives in slums (i.e., 'informal' housing settlements that lack basic infrastructure and utility services), according to UN Habitat. Slums present special challenges to the human immune system, due to their combination of very high population densities, poor sanitation infrastructure, and geographic location, which is disproportionately near the equator. However, they also offer excellent opportunities to understand energetic trade-off dynamics. Within the context of a single large urban area there is often extensive variation in the quality of sanitation infrastructure within slums, along with temporal variation in expected pathogenic loads (via, for example, rainy season floods that expose inhabitants to fecal-contaminated water). We propose measuring total energy expenditure along with several proxy measures of expenditure on specific physiological processes–namely, immune function, fat deposition, sex hormone production, and cognitive function–in the context of slums in Mumbai that vary in their quality of infrastructure. Crucially, these sites have high within-and-across household homogeneity in other behavioral and life history characteristics, which facilitates attribution of changes to local environmental conditions. This project capitalizes on existing field sites in six Mumbai slums and relationships with local NGOs and hospitals.

Using the Diet to Manipulate Microbiome-Generated Methane Production in Real Time: A Case Study of Rats with Relevance to Humans

Marshall D. McCue[1], Kenneth Z. McKenna[1], John R. B. Lighton[1]

[1]Sable Systems International

Methane is a byproduct of methanogenic archaea that oxidize H_2 gas produced by other microflora in the gut. This methane gas is readily absorbed into the into systemic circulation and excreted in the breath down its concentration gradient (similar to CO_2) or may be acutely expelled as flatus. While ruminant animals can generate over 100 liters of methane per day, technological limitations have precluded detailed measurements of methane production and release in humans and other non-ruminants (e.g., rats). We used a high-precision (<1ppb) methane analyzer capable of real-time methane measurements. We then subjected a rat to multiple diet switches, 48h of fasting, and ethanol treatments and continuously measured food/water intake, metabolic rate, and methane release over 26 days. VCO_2 responses were unaffected by diet changes and only decreased slightly during the fasting treatment. Methane release was diminished by some diet treatments and was fully restored by other diets. Ethanol had no observable effects. Methane production followed a circadian cycle whereby total rates were ~50% higher and large flatus events were more frequent during the scotophase. Methane release during flatus varied by >1,000-fold. We confirmed that the vast majority of methane release occurred in the breath and not in the flatus. Finally, we provide evidence that constitutive methane release is positively correlated with overall activity levels. Given the growing number of molecular-based studies investigating how gut microbiota can alter physiological function at higher levels of biological organization this approach promises to provide a powerful new tool to establish causal linkages between microbiome dynamics and whole-animal responses. This experimental approach can easily be modified for human measurements.

Dried blood spots as a method for examining analytes of interest in energetic studies

AA Miller[1], TW McDade[1]

[1]Department of Anthropology and Institute for Policy Research, Northwestern University, Evanston, Illinois

Dried blood spots (DBS) offer an easily implemented method to collect whole blood specimens in a field setting. This method avoids many of the logistic challenges that venous blood collection, storage, and transportation pose and sample collection can be done with relatively little training. This presentation will discuss a DBS field collection protocol and the use of bloodspots for the analysis of two analytes of interest in energetic studies, Leptin and Insulin. Leptin is an adipocyte derived hormone that correlates highly with measures of fatness and plays an important role in energy regulation. Insulin is produced in the pancreas and functions to regulate blood glucose. Both of these analytes can be measured together using two 5 mm DBS discs on a multiplex platform (Meso-Scale Discovery, kit #K15164C-1). These analytes show a high levels of agreement between DBS and serum values in a set of sixty nine matched samples (Leptin: $r = 0.909$, $p < 0.001$; Insulin: $r = 0.976$, $p < 0.001$). Both analytes have acceptable levels of inter and intra-assay variability across low, medium, and high controls (Leptin < 10% and Insulin < 17 % on all measures) and low limits of detection (Leptin = 0.206 ng/mL, Insulin = 77.180 pg/mL). We aim to identify additional analytes of interest to researchers conducting energetic studies in order to validate protocols for use with DBS samples.

Brown adipose tissue is metabolically activated at wide temperature range in Samoans

Alexandra Niclou[1], Lupesina Vesi[2], Mary Arorae[2], New Caledonia Naseri[2], Kima Faasalele Savusa[2], Take Naseri[3], James P DeLany[4], Stephen T McGarvey[5], Anna C Rivara[6], Nicola L Hawley[6], Cara Ocobock[1,7]

[1]Department of Anthropology, University of Notre Dame, Notre Dame, IN
[2]Obesity, Lifestyle and Genetic Adaptations (OLaGA) Study Group, Apia, Samoa
[3]Samoa Ministry of Health, Apia, Samoa
[4]AdventHealth Orlando, Translational Research Institute, Orlando, FL
[5]International Health Institute & Dept of Anthropology, Brown University, Providence, RI
[6]Department of Chronic Disease Epidemiology, Yale School of Public Health, New Haven, CT
[7]Eck Institute for Global Health, University of Notre Dame, Notre Dame, IN

Brown adipose tissue (BAT) is a heat producing organ contributing to non-shivering thermogenesis (NST). NST is activated in response to lower ambient temperatures and its activation rates vary between individuals, populations, and conditions. In this study, we compared inferred BAT activity among participants from Apia, Samoa undergoing one of two cold exposures. We assessed BAT activity by comparing metabolic rate and surface temperatures at the supraclavicular and sternum at thermoneutrality and cold exposure. The Ice Group (n=61, F: n= 37) was exposed to mild cold conditions (15-19°C) by pumping ice water through a cooling suit. The Water Group (n=39, F: n=22) was exposed to temperatures between 21-24°C by using tap water during the cooling period. Thermoneutrality measurements were taken at room temperature (mean:26°C) for both groups. Metabolic rate did not change between thermoneutrality and cold exposures (Ice: P=0.14, Water: P=0.97). Both groups saw significant temperature drops after cooling at the supraclavicular, a BAT location (Ice&Water: P< 0.001), and sternum, a non-BAT area (Ice&Water: P< 0.001). BAT activity was inferred in both cold exposure groups as changes in sternum temperature were significantly greater than changes in supraclavicular temperature upon cold exposure (Ice: P< 0.001, Water: P< 0.001). After cooling neither metabolic rate nor changes in surface temperatures differed between groups. This suggests that NST was activated at relatively wide temperature ranges in this sample. These findings provide evidence that NST may be activated at warmer temperatures than previously thought, reducing the need for ice water during cooling in field-based BAT inferring.

Probability of failure in reaching isotopic equilibrium in urine specimens of older adults

Michele N. Ravelli (ravelli@wisc.edu) [1], Tim Shriver (tshriver@wisc.edu)[1], Dale A. Schoeller (dschoell@nutrisci.wisc.edu)[1]

[1]Biotechnology Center, University of Wisconsin, Madison, WI. Address: 425 Henry Mall, Madison, WI 53706

Background: Even following methodological protocols, subjects' physiological conditions could introduce errors to measurements of isotopic enrichments.

Aim: Determine the association of failure to reach isotopic equilibrium for doubly-labeled water (DLW) with the biological age of humans.

Methods: Urine samples from 2111 subjects (51.8% female, age 14–75 years, BMI 14–65 kg/m2) were gathered from eleven studies and analyzed by the Isotope Ratio Mass Spectrometry Laboratory (Wisconsin-Madison/USA). Isotopic measurements were tested for the delay in achieving an isotopic plateau in the two urine samples collected >3h and at least three voids after dosing. The criteria of failure were defined as a difference of >5% in the isotope enrichment between the last two urine specimens, 1-hour apart. When available, a saliva specimen collected at the same time point as the last urine sample was analyzed to confirm the delay. Simple and adjusted (BMI and sex) logistic regression models using failure in the isotopic equilibrium as a dependent variable tested the association. The age was categorized into three classes: young (<40 years), middle-aged adults (40–59 years), and older adults (≥60 years).

Results: In the adjusted analysis, older adults were three times more likely (OR = 3.22, 95% IC = 1.81–7.02) and middle-aged adults were twice as likely (OR = 2.38, 95% IC = 1.28–5.24) to delay achieving isotopic equilibrium in urine samples than young adults.

Conclusion: These data suggest that older subjects have a higher incidence of a significant delay in urinary isotopic equilibration, which may be associated with post-voided residual urine volume. Isotopic analysis of saliva or plasma specimens, for individuals greater than 60 years, can avoid inaccuracies associated with this delay.

Energy expenditure and neuroendocrine response when acclimatizing to novel and challenging environments

MS Sarma[1], CJ Ocobock[2,3], S Rochelle[4], S Martin[4], LT Gettler[3,5]

[1]Johns Hopkins School of Medicine, Baltimore, MD
[2]Human Energetics Lab, Anthropology, University of Notre Dame, Notre Dame, IN
[3]Eck Institute for Global Health, University of Notre Dame, Notre Dame, IN
[4]National Outdoor Leadership School Rocky Mountain, NOLS, Lander, WY
[5]Hormones, Health, and Human Behavior Lab, Anthropology, University of Notre Dame, Notre Dame IN

In expeditionary environments, ecological and psychological stressors impose intensive demands on human physiology and psychobiological functioning. Key to psychobiological functioning are neuroendocrine systems which play an important mechanistic role in balancing trade-offs between growth, reproduction, and maintenance. Some endocrine axes, like the hypothalamic-pituitary-adrenal (HPA) axis and the hypothalamic-pituitary-gonadal (HPG) axis, and its outputs cortisol and testosterone respectively, are related to energy allocation, including direct effects on metabolic function and behavioral patterns (i.e., how time and energy are expended). However, little is known about the relationship between cortisol and testosterone changes and energy expenditure shifts when individuals are experiencing a novel and challenging environment. Here, we worked with participants (n=71) enrolled in ~90-day expeditions through the American Rockies as part of the National Outdoor Leadership School We measured longitudinal, within-individual changes of cortisol, testosterone, physical activity, and energy expenditure. While physical activity intensity and energy expenditure did not significantly differ between early and late in the course in men and women, during daily activity women's cortisol acutely declined more steeply early in the expedition compared to more muted acute declines later in the expedition. These attenuated cortisol declines in women may reflect the cumulative energetic demands on their bodies across the expedition. These results suggest that there may be physiological differences in how men and women experience intensive conditions, with cortisol's role in energy allocation potentially manifesting differently in women and men's bodies. We anticipate that testosterone output may reveal further nuance on sex-specific energetic outcomes in the expeditionary environment.

Does mitochondrial respiratory chain dysfunction alter cellular and whole-body energy expenditure?

Alexander J. Sercel[1], Gabriel Sturm[1], Shannon Rausser[1], Michio Hirano[2], Dympna Gallagher[2], Edward L. Melanson[3], Marie-Pierre St-Onge[2], Martin Picard[1]

[1]Columbia University Irving Medical Center
[2]Columbia University
[3]University of Colorado Anschulz Medical Campus

Mitochondria are intracellular organelles that sustain life through respiration and ATP production, a process called oxidative phosphorylation (OxPhos). Genetic OxPhos defects cause a spectrum of multi-system mitochondrial diseases where affected patients present with debilitating fatigue, disease, and an average 3-decade reduction in lifespan. However, the pathologic mechanisms of mitochondrial diseases remain unclear. Our meta-analysis of the literature (690 mitochondrial disease patients, 225 healthy controls) revealed that compared to controls, patients exhibit elevated resting heart rate (+10.7%, $p<0.01$), VO2/kg body mass (+30%, $p<0.0001$), and circulating catecholamine levels (+244%, $p<0.05$), and lower BMI (9.8%, $p<0.05$), consistent with, although not providing definitive evidence for, elevated basal metabolic rate (BMR) or total energy expenditure (TEE). To investigate this process at the cellular level, we developed an in vitro lifespan model using patient- and control-derived primary fibroblasts enabling longitudinal measures of energetics and cellular behavior. Consistent with clinical data, compared to controls, OxPhos-deficient fibroblasts exhibited shorter lifespan (-53%, $p<0.072$) and greater total energy expenditure (+91%, $p<0.001$) calculated from oxygen consumption and extracellular acidification measurements. Ongoing work in primary human cells will determine how different intracellular processes contribute to increased ATP demand in hypermetabolic, OxPhos-deficient cells. To translate these findings and accurately profile whole-body energetics in patients with mitochondrial diseases, we will directly quantify BMR and TEE in a cohort of patients with rare, genetically-defined OxPhos defects. Integrating in vitro and whole-body energy expenditure measurements can lead to mechanistic insights into the origin of evolutionary-conserved energetic constraints on human health.

Beyond Nutrition and Activity: proposing demographic-specific energy expenditure analysis for western lowland gorillas (*Gorilla gorilla gorilla*) in North American Zoos

Rhiannon L. Schultz[1]

[1]Department of Anthropology, University of Georgia

Despite variation in feeding programs across institutions, captive gorillas exhibit a range of health issues including hypercholesterolemia, hypertension, obesity, and diabetes, with heart disease as their leading cause of mortality. Previous studies have focused on the nutritive quality of prescribed diets but have not analyzed the actual nutrient ingestion of individuals. Physical activity is often used as a proxy to estimate energy and nutritional needs, but few studies have analyzed gorilla total energy expenditure and how it may change across age, sex, and health demographics. I study the nutritional profiles and activity patterns of male western lowland gorillas (*Gorilla gorilla gorilla*) living in North America zoological institutions, and investigate how their risk of cardiovascular disease changes across life stages and environmental factors. Pilot data collected from summer 2021 to spring 2022 examined nutrient intake, physical activity, and metabolic and cardiac health status of subjects (n = 5) and suggests that there are age-, sexual maturation-, and health-specific factors influencing nutrition and physical activity differences among captive males. Additionally, captive adults with cardiac disease dedicated less time to feeding and spent more time inactive than do wild adults, suggesting health and/or management implications for activity patterns. The next stages of this research will begin in summer 2022 and include increasing sample size (n ≈ 90 gorillas) and observation time per individual, expanding data collection to more institutions (n ≈ 15), and using the doubly labeled water method to assess total energy expenditure in a subset of subjects representing various demographic categories.

Cardiorespiratory Fitness Monitoring Using Wearables

Md Mobashir Hasan Shandhi[1]; Jessilyn P. Dunn[1,2]

[1]Biomedical Engineering, Duke University
[2]Biostatistics and Bioinformatics, Duke University

Heart failure (HF) is a chronic and progressive disease affecting roughly 6.5 million Americans. HF requires longitudinal outpatient monitoring to track disease progression and to guide appropriate interventions. Exercise intolerance and limited physical activity capacity are hallmark symptoms of HF and are used to track disease progression. Cardiopulmonary exercise testing (CPET) is the most comprehensive exercise test designed to measure exercise capacity and quantify the degree of cardiac impairment in HF. While CPET yields accurate prognoses for the HF patient's survival, it also requires a specialized environment, obtrusive equipment, and trained professionals. The resulting infrequent testing (once or twice a year) means that key information indicating worsening HF is often missed until serious events occur. An alternative to CPET that estimates exercise capacity from activities of daily living (ADL) would enable continuous longitudinal monitoring of HF outside of the clinic, but no such system exists today. Here, we address the critical need to develop an unobtrusive and inexpensive technology that can be utilized to track the progression of HF continuously and outside of a clinical setting.

The long-term goal of our collaborative effort is to develop a novel multimodal wearable technology as an unobtrusive, inexpensive, and scalable alternative to CPET for remote monitoring of HF. We have made substantial progress towards this goal in our recent studies where we used a wearable patch to estimate instantaneous oxygen uptake (VO2) (R^2=0.76) and the clinical status (e.g., stage C and D HF) (AUC-ROC=0.92) during CPET in patients with HF. Further, we found we can estimate instantaneous VO2 during ADL in healthy individuals (treadmill walking R^2=0.77; outdoor walking R^2=0.64), indicating the potential for wearables as a viable alternative to CPET. We have also demonstrated that peripheral tissue oxygen saturation incorporated with portable gas analyzers during submaximal exercise tests can be used to assess cardiorespiratory fitness (CRF) in patients with HF. The overall objective of our present collaborative effort is to leverage our prior efforts to advance the state of the art of wearable CRF monitoring and address the key remaining challenges for the real-world implementation of such technology. The technology and corresponding algorithms are expected to transform remote monitoring and management of patients with HF by informing CRF and HF clinical status from ADL continuously and outside of clinical settings.

Persistent hypermetabolism and longitudinal energy expenditure in critically ill patients with COVID-19

John Whittle[1], Jeroen Molinger[1], David MacLeod[1], Krista Haines[2], Paul E. Wischmeyer[1,2]* for the LEEP-COVID Study Group

[1]Division of Critical Care, Human Pharmacology and Physiology Laboratory (HPPL), Department of Anesthesiology, Duke University School of Medicine, DUMC, Box 3094 Mail # 41, 2301 Erwin Road, 5692 HAFS, Durham, NC 27710, USA
[2]Division of Trauma Critical Care, and Acute Care Surgery, Department of Surgery, Duke University School of Medicine, Durham, NC, USA

COVID-19 infection results in respiratory failure requiring ICU care in a small, yet significant, number of patients. The longitudinal metabolic phenotype and energy expenditure of this novel pandemic disease has yet to be described. As a marked and often prolonged, systemic inflammatory response (SIRS) has been suggested to be a hallmark of severe COVID-19 infection, we hypothesized a prolonged hypermetabolic state would evolve over ICU stay that would persist beyond the 7–10 day hypermetabolic phase.

Behavior and energetics of parenting in a biparental, neotropical primate

David B. Wood[1], Herman Pontzer[2], Karen Bales[3], Eduardo Fernandez-Duque[1]

[1]Yale University
[2]Duke University
[3]California National Primate Research Center

It has been hypothesized that cooperative breeding is central to the evolution of the human life history, but disentangling the relationships between the energetic costs of the different forms of care provided by many care givers is challenging. Biparental care offers a simplified form of cooperative breeding since maternal care is only modified by the care of one individual: the father. I will investigate the relative contributions of male and female titi monkey parents (*Plecturocebus cupreus*) to the care of their infants. I hypothesize that males do not compensate for maternal energy invested in their offspring during gestation, a time when they cannot provide direct care to the infant, but do compensate for maternal investment following birth, when they can. Therefore, I predict that following the birth of the infant both parents' total energy expenditure (TEE) will be similar until the end of infant care. I will test this prediction using a combination of behavioral data, and energetic data derived from doubly labeled water and accelerometers, collected from captive titi monkeys at the California Primate Research Center in Davis, CA. Throughout the entire period of infant care, I will collect behavioral data from 10 reproductive pairs, activity data from 10 reproductive and 10 nonreproductive pairs, and energetic data from 10 reproductive and 4 nonreproductive pairs. This design allows me to make inferences about the energetic investment parents make during infant care since measures of TEE will be in the context of behavior and activity, and comparable to a nonreproductive baseline.