

Invited Articles

PENSAR EN MOVIMIENTO:
Revista de Ciencias del Ejercicio y la Salud
EISSN 1659-4436
Vol. 11, No. 2, pp. 1- 13



ENERGY THERMODYNAMICS REVISITED: ENERGY INTAKE STRATEGIES FOR OPTIMIZING ATHLETE BODY COMPOSITION AND PERFORMANCE

Dan Benardot, PhD, DHC, RD, LD, FACSM
dbenardot@gsu.edu; www.foodandsport.com; @DrDanBenardot
Professor, Department of Nutrition. Professor, Department of Kinesiology and Health
Georgia State University
Atlanta, GA USA

Manuscript received: 07/07/2013; resubmitted: 25/10/2013, 15/11/2013; accepted: 15/11/2013;
published: 18/12/2013

ABSTRACT

Benardot, D. (2013). Energy Thermodynamics Revisited: Energy Intake Strategies for Optimizing Athlete Body Composition and Performance. **PENSAR EN MOVIMIENTO: Revista de Ciencias del Ejercicio y la Salud**, 11 (2), 1-13. A key feature of physical activity is that it results in an increased rate of energy expenditure and, as a result of metabolic inefficiencies that lead to high heat production, an increase in the requirement to dissipate the added heat through sweat. Nevertheless, studies assessing food and fluid intakes of athletes commonly find that they fail to optimally satisfy their daily predicted requirements of both energy and fluid, causing them to perform at levels below their conditioned capacities. To some extent, this problem results from an excess reliance on the sensations of 'hunger' and 'thirst' to guide energy and fluid intakes. However, there are also common misunderstandings of the best nutrition strategies for achieving optimal body composition and performance. Athletes in all sports should strive to improve the strength-to-weight ratio to enable an enhanced ability to overcome sport-related resistance, but this may be misinterpreted as a need to achieve a lower weight, which may result in an under-consumption of energy through restrained eating and special 'diets'. The outcome, however, is nearly always the precise opposite of the desired effect, with lower strength-to-weight ratios that result in an ever-increasing downward spiral in energy consumption. This paper focuses on within-day energy balance eating and drinking strategies that are now successfully followed by many elite-level athletes, including long-distance runners, sprinters, gymnasts, figure skaters, and football players. These strategies can help athletes avoid the common errors of under-consumption while simultaneously improving both body composition and performance.

Keywords: Energy balance; body composition; weight.

RESUMEN

Benardot, D. (2013). Replanteamiento de la termodinámica energética: estrategias de ingesta de energía para la optimización de la composición corporal y el rendimiento en atletas. **PENSAR EN MOVIMIENTO: Revista de Ciencias del Ejercicio y la Salud**, 11 (2), 1-13. Un aspecto clave de la actividad física es que produce un aumento en la tasa de gasto energético y, como resultado de las ineficiencias metabólicas que conducen a una alta producción de calor, produce un aumento en la necesidad de disipar el calor adicional con ayuda de la sudoración. No obstante, los estudios que valoran la ingesta de alimentos y bebidas en los atletas concluyen que estas personas no logran satisfacer de manera óptima su requerimiento diario previsto de energía ni de líquido, provocando que su rendimiento sea inferior con respecto a lo que su capacidad permitiría. Este problema obedece, en cierta medida, a una dependencia excesiva de las sensaciones de hambre y sed como guías para la ingesta de energía y líquido. Además, existen malentendidos sobre las mejores estrategias nutricionales para alcanzar tanto una composición corporal adecuada como un rendimiento óptimo. Todos los atletas, independientemente de su disciplina deportiva, deberían esforzarse por mejorar su relación fuerza-peso para facilitar una mayor habilidad de superar la resistencia asociada a su deporte; sin embargo, esto se puede interpretar incorrectamente como la necesidad de disminuir el peso, lo cual puede provocar el consumo insuficiente de energía a través de restricciones en la alimentación y *dietas* especiales. El resultado es, casi siempre, el opuesto de lo que se pretendía alcanzar, puesto que se dan relaciones más bajas de fuerza-peso que a su vez producen una espiral descendente en el consumo energético. Este manuscrito se concentra en las estrategias de equilibrio diario de alimentación e ingesta de líquido que utilizan actualmente con éxito muchos atletas de élite, incluyendo a corredores de larga distancia, velocistas, gimnastas, patinadores artísticos y jugadores de fútbol americano. Dichas estrategias pueden ayudar a los atletas y así evitar los errores comunes de baja ingesta, al mismo tiempo que mejoran su composición corporal y rendimiento.

Palabras Clave: balance energético, composición corporal, peso.

Introduction

All athletic endeavors cause an increased rate of energy expenditure, a change in the energy substrate utilization, altered vitamin and mineral requirements, and an enhanced requirement to dissipate the heat produced as a result of the exercise. The efficiency of converting burned fuel to muscular movement, estimated to be 20-40%, results in a great deal of exercise associated heat production. Since humans cannot acquire additional heat, exercise mandates the production of a large amount of heat removing sweat (Burke, [2001](#); Maughan & Noakes, [1991](#)). Physical activity, therefore, increases both energy and fluid requirements. Despite these seemingly simple exercise-associated requirements, surveys assessing food and fluid intakes have found that physically active people commonly fail to optimally satisfy the increased needs of both energy and fluid (Hawley & Burke, [1997](#); Hubbard, Szlyk & Armstrong, [1990](#)). To exacerbate this problem, it has been found that there is a tendency to supply the energy and fluids after they are most needed (i.e., post-loading), resulting in compromised performance and an undesired change in body composition (Deutz, Benardot, Martin & Cody, [2000](#); Saltzman & Roberts, [1995](#)). Several possibilities exist for why athletes fail to optimally

satisfy total energy and fluid needs, including a poor understanding of what foods and beverages are best to consume; inadequate availability of foods and beverages before, during, and after exercise; a sport-specific tradition that perpetuates inadequate eating and hydration habits; and a tendency for athletes to model behavior after those who have excelled in the sport even if their food/beverage consumption behaviors are less than optimal (Benardot, [2007](#)).

Many athletes also have a level of eating anxiety, with a fear that eating exercise-appropriate foods and beverages will negatively alter body composition by increasing weight (Vardar, Vardar & Kurt, [2007](#); Haase, Prapavessis & Owens, [2002](#); Krane, Waldron, Stiles-shiple & Michalenok, [2001](#)). To some extent, there is confusion with what to eat and drink because of a common misuse of terms. For example: high body fat does not mean high body weight, leanness is not the same as thinness, and a higher weight may be a very good thing if it is the result of more lean mass that can improve the strength-to-weight ratio (Benardot, [2007](#)). The coach who insists that his/her athlete lose five pounds may be dismayed at the performance outcome if the majority of that weight comes from muscle and not fat. This same athlete who gained five pounds of muscle and lost five pounds of fat would be the same weight but with a better strength-to-weight ratio. This athlete would also appear smaller (an advantage in certain 'appearance' sports) because muscle is denser than fat, and would likely also have better endurance because there is less non-muscle 'baggage' to move. Put simply, the failure of many physically active people to optimally consume fluid and energy may be the direct result of using an inappropriate metric, weight, as the sole measure of performance readiness. It also may be due to a misunderstanding of energy thermodynamics as it relates to humans.

Energy Thermodynamics: Macro-Economic View

The traditional view of energy balance involves a macroeconomic view of the human system: A 24-hour energy intake that equals a 24-hour energy expenditure results in perfect energy balance, a state that is associated with weight stability (See [Figure 1](#)). It is also understood that a positive energy balance (i.e., relatively more energy consumed than expended) mandates that the excess energy be stored, resulting in a higher weight, and that a negative energy balance (i.e., relatively less energy consumed than expended) mandates that the difference in energy must be provided by body tissues, resulting in lower weight (Melby & Hickey, [2005](#)). This system of energy thermodynamics implies that a significant reduction in energy intake (often described as 'dieting') results in weight loss, but the belief that it also results in an improved body profile and body composition does not stand up to scrutiny. There is evidence that dieters (i.e., anyone failing to adequately satisfy energy needs) commonly experience a return to the original weight, but the resultant weight has lower metabolic mass and higher fat mass (Saltzman & Roberts, [1995](#); Wing & Phelan, [2005](#)).

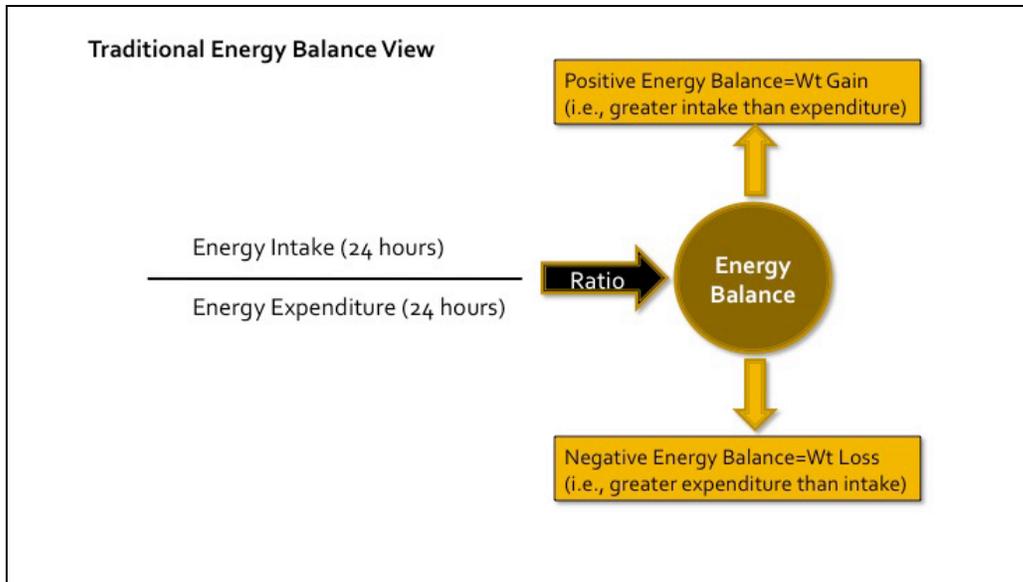


Figure 1. Macroeconomic View of Energy Balance
Prepared by the author

This excessively simplistic view of energy balance, which ignores the human hormonal responses to real-time changes in energy balance, has a standard kcal-to-weight relationship that is commonly used to predict weight change in both athletes and obese people: 3,500 kcal = 1 pound (14,644 kJ = 0.454 kg). That is, a 3,500 kcal positive energy balance will result in a 1-pound increase in weight, and a 3,500 kcal negative energy balance will result in a 1-pound decrease in weight. Although this relationship is a standard feature of virtually all books and book chapters that discuss energy balance, it has never been found to be correct. A recent review of energy balance has found that this relationship is not, in fact, accurate (Hall et al., 2012). They point out that it is fallacy to think that small changes in lifestyle have the capacity to reverse obesity, and show that walking to lose 100 kcal more each day should result in 50 lb. of weight loss in 5 years, but the actual loss is typically a mere 10 lb. A new on-line model presented by the National Institutes of Health (U.S.) has incorporated this point by including new set point plateau norms (<http://bwsimulator.niddk.nih.gov>). This system finds that a 40 kcal/d permanent reduction in energy intake should result in ~20 lb. weight loss in 5 years, but the actual predicted weight loss is only 4 lb. because the body has a compensatory response that is not considered in the standard (i.e., 3,500 kcal = 1 lb.) energy balance prediction.

Hormonal Response to Energy Balance Shifts

There are data to suggest that relatively large doses of refined/simple carbohydrates may result in hyperinsulinemia which, unlike a normoinsulinemic response, fails to shut down the appetite controlling hormone ghrelin (Saad et al., 2002; Knerr, Gröschl, Rascher & Rauh, 2003; Blom et al., 2005). The continued ghrelin presence would result in greater food consumption and, if this produces a high positive energy balance, would result in higher weight. Without an anabolic stimulus to increase muscle, this in turn would result in higher body fat. The

carbohydrate explanation for hyperinsulinemia is likely to be incomplete and potentially misleading, as there are multiple causes of hyperinsulinemia in addition to the consumption of high glycemic meals that typically contain a high proportion of refined carbohydrates or sugar. For instance, an eating pattern that is infrequent and allows blood sugar to drop below normal levels may also result in a hyperinsulinemic response at the next eating opportunity (Bertelsen et al., [1993](#); Fåibry & Tepperman, [1970](#)). Insulin is produced exponentially to the caloric load of the food consumed, so eating an excessively large meal (regardless of its composition) would also result in excess insulin production with the concomitant increase in fat and, because of the associated maintenance of ghrelin, more total energy intake and weight (Toshinai et al., [2001](#); Cohn, Berger & Norton, [1968](#)). Higher total body fat or higher abdominal fat, regardless of the food consumed, also results in hyperinsulinemia and all of its sequellae (Evans, Hoffman, Kalkhoff, & Kissebah, [1984](#); Peiris, Mueller, Smith, Struve, & Kissebah, [1986](#)). So, while it is true that carbohydrates play a special role in insulin production, there are multiple other causes of hyperinsulinemia that are independent of macronutrient distribution and these causes cannot be ignored if attempting to understand how energy balance dynamics influence weight and body composition.

An additional problem is that the calculation of energy balance using the 24-hour macroeconomic view makes the assumption that the time of day used to assess the prior 24-hours is irrelevant. The typical data collection strategy for such an assessment is to ask a client/athlete for the immediate prior 24-hour energy intake and expenditure regardless of the time of day the client is with you. This assumes that energy balance at that precise point of time is the same for the entire 24-hours that preceded it. However, the within-day energy balance curve is not flat, so the time of day that the client/athlete is assessed creates differences in the energy balance calculation. Also, meals are not always consumed at the same times. A later dinner that is consumed early in the 24-hour assessment period could lead to two dinners being included in the same analysis period, resulting in an apparent large 24-hour energy balance surplus. An early dinner early in the 24-hour assessment period and a late dinner late in the same 24-hour assessment period could exclude both dinners and make it appear as if the client is in a chronic energy balance deficit. The resulting energy balance conclusion would, therefore, be entirely different for the same person, depending on the time of day the evaluation took place.

It is possible for a person to appear to be in nearly perfect energy balance at the end of a 24-hour assessment period, but to have arrived at this point with extremely large energy balance surpluses or deficits that could impact body composition. A source of concern with the macroeconomic model for energy balance is the lack of importance placed on how energy is consumed or how it is expended. This model assumes that a person requiring 2000 kcal/day (8368 kJ/day) to satisfy energy requirements could consume that energy without regard to meal size or eating frequency, and the energy balance influence on weight or body composition would be the same. This person could, for instance, have a 2000 kcal breakfast and eat nothing else the remainder of the day to satisfy the energy requirement; they could have a 2000 kcal dinner and eat nothing else prior to that dinner; or they could have four 500 kcal meals during the day. The 24-hour macroeconomic model assumes that the endocrine system only takes action at the point of assessment, and that the outcomes in body composition and weight would be the same, but they are not. The large breakfast would cause the person to spend the

majority of the day in an energy balance surplus, with excess fat storage the likely outcome; the large dinner would cause the person to spend the majority of the day in an energy balance deficit, with catabolism of lean tissue and a relatively higher fat storage; and the frequent meal eater is more likely to sustain the metabolic mass and the fat mass. An example of this can be found in an assessment of an elite figure skater, whose ending energy balance was very close to perfect, but who achieved a large energy balance deficit while arriving at the end-of-day energy balance point (Benardot, [2007](#)). The corrective action was to adjust the consumed energy during the day to avoid the large energy balance deficit while maintaining total energy intake as it was. This strategy resulted in lower body fat percent for this subject, in a way that was consistent with the findings of Deutz et al. ([2000](#)). At no time was the recommendation made to increase or lower total energy intake, but rather to change the timing and amount of foods consumed to better sustain energy balance throughout the day and positively influence the hormone response.

The traditional 24-hour energy balance model is not capable of considering within-day fluctuations in energy balance and there are studies illustrating these very issues. It was found that muscle catabolism occurs with inadequate fuel provision as an adaptation to the poor fuel delivery and as a consequence of higher cortisol production (Jenkins et al., [1989](#); Iwao, Mori, & Sato, [1996](#)). Infrequent eating and large bolus meals result in higher body fat storage, even if total caloric intake is the same, largely as a result of greater insulin production from the larger meals (Fogteloo et al., [2004](#); Deutz et al., [2000](#)). Insulin, blood sugar, and leptin are better controlled with frequent smaller feedings that dynamically match energy requirement (Leibel, Rosenbaum, & Hirsch, [1995](#); Hawley & Burke, [1997](#)). The exerciser who fails to satisfy the dynamic need for energy and develops low blood sugar will go into a state of gluconeogenesis. This will result in the likely breakdown of lean tissue to release alanine to the liver where the alanine-glucose cycle can manufacture glucose to, among other things, sustain normal brain function. An early study found that after only 40 minutes of strenuous activity, free serum alanine could increase by 60 to 90% or even more if the exercise occurs with low blood sugar (Felig & Wahren, [1971](#)). More recent studies have also found that cortisol is elevated if exercise proceeds with a failure to consume a carbohydrate beverage, likely resulting in a negative within-day energy balance and in low blood sugar (Nieman et al., [2001](#)). Cortisol is known to be catabolic to both bone and muscle, resulting in higher stress fracture risk and higher body fat percent (Jenkins et al., [1989](#); Canalis, Mazziotti, Giustina, & Bilezikian, [2007](#); Dimitriou, Maser-Gluth, & Remer, [2003](#)). One must ask, "Why would an athlete exercise in a way that breaks down muscle and bone when their goal is to reduce exercise-associated risks and enhance muscle function?" Yet, if the traditional 24-hour energy balance view is followed, this is all too possible.

Energy Thermodynamics: Microeconomic View

Energy balance in humans is complex, and involves multiple issues on the 'energy in' side of the equation, including meal size, meal frequency, diet quality, and net absorption of the foods consumed. The 'energy out' side of the equation also must consider several variables, including diet quality, metabolism, physical activity, meal frequency, and the thermic effect of food (Hall et al., [2012](#)). Once all of these factors are considered, the impact on the endocrine

system, including insulin, leptin, ghrelin, and peptide YY must also be taken into account. These energy balance feedback mechanisms make it difficult to alter weight simply by changing the delivery or expenditure of energy, as 'the system' is made to sustain the body as it is. For instance, while leptin has the effect of reducing food intake, increasing energy expenditure, increasing fat catabolism, reducing plasma glucose and lowering body weight, ghrelin has the precise opposite effect in each of these areas. Some factors, however, may cause leptin and ghrelin to work in unexpected ways. It is also known that reduced meal frequency can have an unexpected influence on leptin and ghrelin. Dietary trends that coincide with the steep obesity velocity curve include larger food portion sizes, consumption of fast foods with hidden fats, and decreased meal frequency (Koletzko & Toschke, [2010](#)). All of these have an influence on ghrelin and leptin. Decreased meal frequency is associated with greater daily energy consumption, possibly from an up-regulation of appetite and/or a tendency for greater fat consumption (Viskaal-van Dongen, deGraaf, Siedelink, & Kok, [2009](#); Smith et al., [2010](#)). Viskaal van Dongen et al. ([2009](#)) found in studies of 57 participants (study 1) and 51 participants (study 2) that visible fats in meals resulted in a lower total energy intake than hidden fats because of altered sensory signals. Smith et al. ([2010](#)) found that meal skipping has an influence on obesity. They assessed a large sample of people who did not typically skip breakfast as children or adults (n = 1359), those who skipped breakfast only in childhood (n = 224), those who skipped breakfast only in adulthood (n = 515), or those who skipped breakfast in both childhood and adulthood. The chronic breakfast skippers had significantly higher fasting insulin, serum LDL, and waist circumference. Even when adjusting for diet quality, these differences persisted.

It has also been found that the increased energy intake associated with infrequent eating is not matched with higher activity, resulting in a higher body fat level (Franko et al. [2008](#); Berkey, Rockett, Gillman, Field, and Colditz, [2003](#)). Franko et al. ([2008](#)) found, after studying girls between the ages 9-19 for over 10 years, that the subjects who consumed 3+ meals on more days had lower overweight and obesity rates than girls with lower meal frequency. Berkey et al. ([2003](#)), studying a cohort of more than 14,000 boys and girls found that eating breakfast (i.e., increasing eating frequency) was an important strategy for avoiding obesity.

Avoiding hyperinsulinemia, either through preventing hunger (a direct result of infrequent eating and poor within-day energy balance) or eluding the consumption of high glycemic foods is useful in controlling the appetite stimulating hormone ghrelin. Anderwalt et al. ([2003](#)) found that ghrelin was unchanged in type 2 diabetics following insulin treatment, but a rise in serum insulin that occurs following a meal had the effect of suppressing ghrelin and reducing appetite in non-diabetics. Assessing a small group (n = 5) of young adult males, Solomon, Chambers, Jeukendrup, Toogood, and Blannin ([2008](#)) also found that the postprandial fall in ghrelin is likely due to the rise in insulin, but that this relationship does not exist with the hyperinsulinemia associated with insulin resistance. Isacco et al. ([2010](#)) studied a group of 278 healthy French schoolchildren, between 6 and 8 years old and found that skipping breakfast and consuming sugar-sweetened beverages while watching TV are both likely factors in unsuppressed ghrelin, hyperinsulinemia, or both, and that these behaviors were associated with significantly higher BMI, sum of 4 skinfolds, and waist circumference.

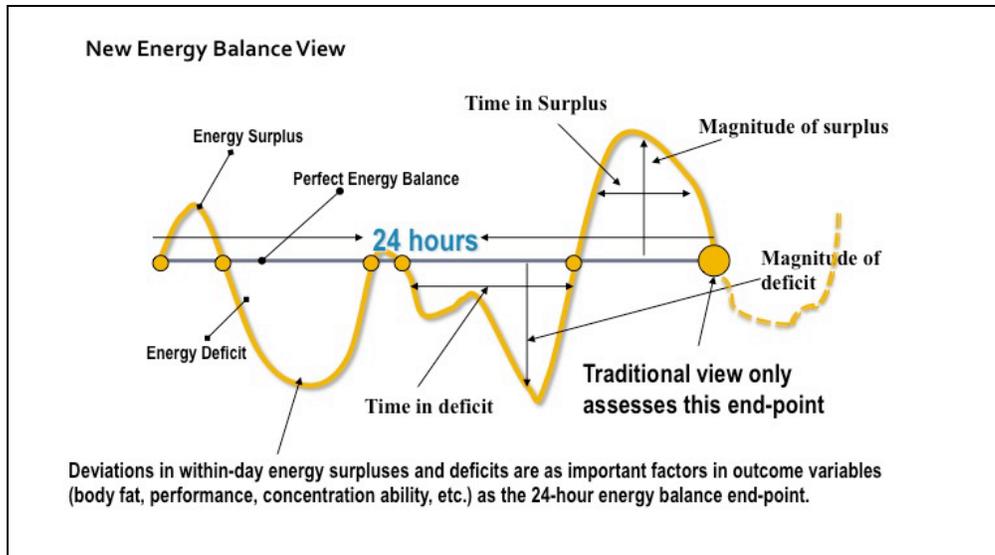


Figure 2. Macroeconomic view of energy balance. Prepared by the author. Note: The commonly measured 24-hour energy balance end-point fails to account for fluctuations in energy balance during the day. These within-day energy balance deviations are associated with differences in body composition.

A concern with the macroeconomic view of energy balance is the assumption that an energy balance achieved at the end of a 24-hour period is perfectly sustained for the entire 24 hours that precedes it. However, as demonstrated in [Figure 2](#), there are natural peaks and valleys in energy balance throughout the day, and it has been found that wide deviations from perfect energy balance during a 24-hour period are associated with higher body fat %, even if energy balance is achieved at the end of that 24-hour period. Deutz et al. ([2000](#)) found, in studying female elite artistic and rhythmic gymnasts ($n = 42$; mean age 15.5 yr.), and middle- and long-distance runners ($n = 20$; mean age 26.6 yr.), that large energy balance deficits achieved by either group of athletes were associated with significantly higher body fat levels (gymnasts: $r = .508$; $p < .001$ and runners: $r = .461$; $p = .041$), despite ending the day in a relatively good energy balanced states.

Using NutriTiming® (NutriTiming LLC, Atlanta, GA)¹, a recent assessment of U.S. female national team figure skaters ($n = 10$; Mean age = 18.75) used the microeconomic model to assess energy balance, and found a strong and statistically significant association ($r = .745$; $p = .013$) between the hours spent in an energy balance deficit exceeding -400 kcal and body fat % (Benardot unpublished data, 2012). The greater the amount of time spent in a severe energy balance deficit, the higher the body fat %, and the greater the amount of time spent in energy balance ± 400 kcal, the lower the body fat %. Importantly, it was also found that the traditional end-of-day 24-hour energy balance was not statistically related to body fat %. This same group was assessed for bone density, serum vitamin D, and serum cortisol. Higher serum cortisol, which is known to become elevated with negative energy balance and low blood

¹ Disclosure: Dr. Benardot is inventor of NutriTiming® (NutriTiming.com and Apple App Store), and scientific advisor to NutriTiming LLC.

glucose, was significantly associated with lower BMD ($r = -0.664$; $p = .026$) and higher body fat % ($r = .657$; $p = .020$). By contrast, serum vitamin D was not significantly associated with either BMD or body fat % in this elite skater population (Grages, [2013](#); Stafford, [2005](#)). A study of children ($n = 12$; age range 8-14) also found that end-of-day 24-hour energy balance was not associated with body fat %, while more time spent in an energy balance deficit was significantly associated ($r = .914$; $p < .001$) with higher body fat % (Delfausse, [2012](#)). Once again it was found that children who managed to spend a great amount of time during the day with small deviations in energy balance were leaner. A group of exercising middle-age women ($n = 20$) were assessed for menstrual status, and it was found that amenorrhea was associated with spending more time in a catabolic state ($r = .463$; $p = .04$), and also found no relationship between end-of-day energy balance and amenorrhea (Friel & Benardot, [2011](#)).

A recent review of studies assessing the relationship of protein intake and sarcopenia found a similar result, with the suggestion that sustaining a steady intake of high-quality protein (between 25-35 grams per meal) at standard 3-meal intervals throughout the day is far more effective at maintaining or increasing muscle mass than large end-of-day protein intakes (Paddon-Jones, & Rasmussen, [2009](#)). A reassessment of athlete protein intakes using this model is warranted, as it appears that many athletes with relatively high protein intakes exceeding 2 to 3 $\text{g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$, may actually have inadequate protein intakes when maximal protein utilization rates ($\sim 30\text{-}35$ g protein per meal) are considered. The extremely high single-meal protein and energy intakes seen in some athletes, often at levels exceeding 100 g protein and 4,000 kcal, provide protein and energy at levels that are metabolically inefficient and more likely to increase fat mass than muscle mass. Once again, the 24-hour model for energy/nutrient intake and expenditure fails to optimally provide actionable information.

Summary

The within-day energy balance and within-day energy substrate studies, coupled with the poor predictive ability of the traditional 24-hour energy balance model, suggest that a new within-day energy balance model should be used (See [Figure 3](#)). This model considers both time spent in a catabolic and anabolic energy balance state, and the magnitude of the energy balance surpluses and deficits to predict body composition and, ultimately, weight outcomes. Importantly, by incorporating time spent in different energy balance zones, this model may be more useful in predicting the endocrine response to energy balance inadequacies and surpluses. Sports nutrition practitioners may devise their own practical ways of applying the model, or use the existing resources for that purpose.

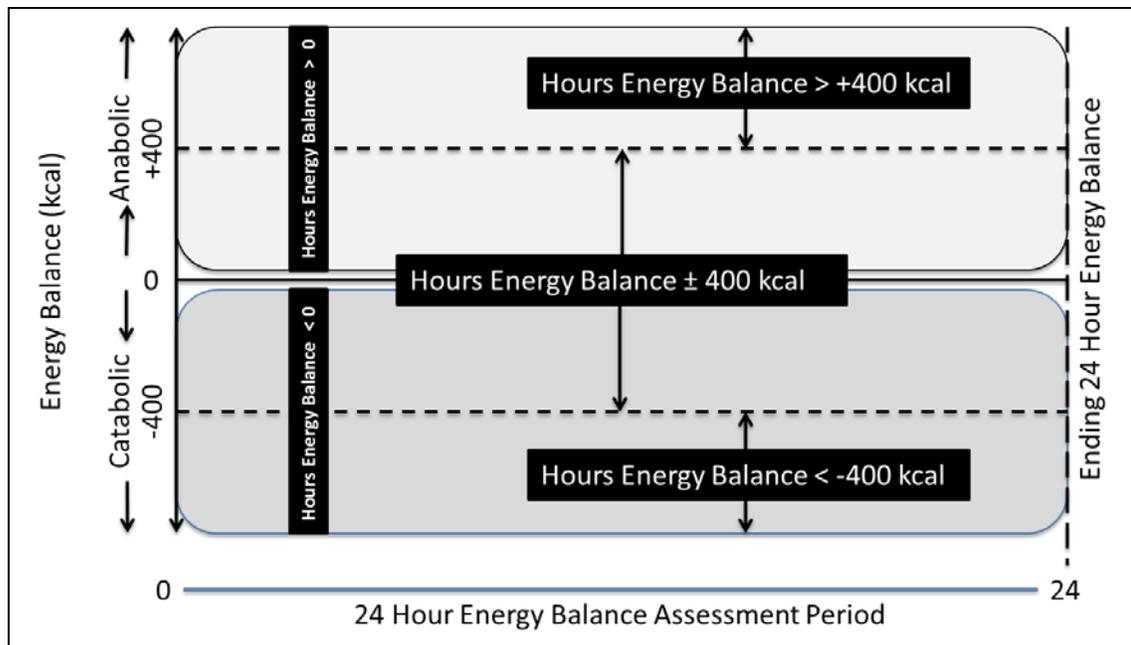


Figure 3. A new model for energy balance assessment. Prepared by the author.
Note: 400 kcal = 1,674 kJ

This model also enables the consideration of an important understanding of energy imbalances: The body's reaction to an inadequate energy intake is to reduce the tissue that *needs* energy. This is a perfectly logical physiological adaptation to the inadequate provision of fuel that serves to diminish an athlete's capacity to improve. Ideally, there should be a *dynamic* relationship between the need for energy and nutrients, and the provision of energy and nutrients to optimize body composition, weight, and performance.

References

- Anderwald, C., Brabant, G., Bernroider, E., Horn, R., Brehm, A., Waldhäusl, W. & Roden, M. (July, 2003). Insulin-dependent modulation of plasma ghrelin and leptin concentrations is less pronounced in type 2 diabetic patients. *Diabetes*, 52(7), 1792-1798. doi: [10.2337/diabetes.52.7.1792](https://doi.org/10.2337/diabetes.52.7.1792)
- Benardot, D. (July/August, 2007). Timing of energy and fluid intake: New concepts for weight control and hydration. *ACSM Health & Fitness Journal*, 11(4), 13-19. doi: [10.1249/01.FIT.0000281226.23643.de](https://doi.org/10.1249/01.FIT.0000281226.23643.de)
- Berkey, C. S., Rockett, H. R. H., Gillman, M. W., Field, A. E. & Colditz, G. A. (2003). Longitudinal study of skipping breakfast and weight change in adolescents. *International Journal of Obesity*, 27, 1258-1266. doi: [10.1038/sj.ijo.0802402](https://doi.org/10.1038/sj.ijo.0802402)
- Bertelsen, J., Christiansen, C., Thomsen, C., Poulsen, P.L., Vestergaard, S., Steinov, A., . . . Hermansen, K. (January, 1993). Effect of meal frequency on blood glucose, insulin, and free fatty acids in NIDDM subjects. *Diabetes Care*, 16(1), 4-7. Retrieved from <http://care.diabetesjournals.org/content/16/1/4.full.pdf>
- Blom, W. A. M., Stafleu, A., de Graaf, C., Kok, F. J., Schaafsma, G., & Hendriks, H. F. J. (February, 2005). Ghrelin response to carbohydrate-enriched breakfast is related to insulin. *The American Journal of Clinical Nutrition*, 81(2), 367-375. Retrieved from <http://ajcn.nutrition.org/content/81/2/367.abstract#fn-1>

- Burke, L. M. (2001). Energy needs of athletes. *Canadian Journal of Applied Physiology*, 26(suppl), S202-S219. doi: [10.1139/h2001-055](https://doi.org/10.1139/h2001-055)
- Canalis, E., Mazziotti, G., Giustina, A., & Bilezikian, J. P. (2007). Glucocorticoid-induced osteoporosis: pathophysiology and therapy. *Osteoporosis International*, 18(10), 1319–1328. doi: [10.1007/s00198-007-0394-0](https://doi.org/10.1007/s00198-007-0394-0)
- Cohn, C., Berger, S., & Norton, M. (February, 1968). Relationship between meal size and frequency and plasma insulin response in man. *Diabetes*, 17(2), 72-75. doi: [10.2337/diab.17.2.72](https://doi.org/10.2337/diab.17.2.72)
- Delfausse, L. (2012). *Within-Day Energy Balance in Children and Adolescents*. (Unpublished Master's Thesis). Georgia State University, U.S.A.
- Deutz, B., Benardot, D., Martin, D., & Cody, M. M. (March, 2000). Relationship between energy deficits and body composition in elite female gymnasts and runners. *Medicine & Science in Sports & Exercise*, 32(3), 659-668. Retrieved from http://journals.lww.com/acsm-msse/Abstract/2000/03000/Relationship_between_energy_deficits_and_body.17.aspx
- Dimitriou, T., Maser-Gluth, C., & Remer, T. (March, 2003). Adrenocortical activity in healthy children is associated with fat mass. *The American Journal of Clinical Nutrition*, 77(3) 731–736. Retrieved from <http://ajcn.nutrition.org/content/77/3/731.short>
- Evans, D. J., Hoffman, R. G., Kalkhoff, R. K., & Kissebah, A. H. (January, 1984). Relationship of body fat topography to insulin sensitivity and metabolic profiles in premenopausal women. *Metabolism*, 33(1), 68-75. Retrieved from <http://www.sciencedirect.com/science/article/pii/0026049584901641>
- Fáibry, P. & Tepperman, J. (August, 1970). Meal frequency - A possible factor in human pathology. *The American Journal of Clinical Nutrition*, 23(8), 1059-1068. Retrieved from <http://ajcn.nutrition.org/content/23/8/1059.short>
- Felig, P. & Wahren, J. (December, 1971). Amino acid metabolism in exercising man. *The Journal of Clinical Investigation*, 50(12), 2703-2714. doi: [10.1172/JCI106771](https://doi.org/10.1172/JCI106771).
- Fogteloo, A. J., Pijl, H., Roelfsema, F., Frölich, M. & Meinders, A. E. (2004). Impact of meal time and frequency on the twenty-four-hour leptin rhythm. *Hormone Research in Pediatrics*, 62, 71-78. doi: [10.1159/000079326](https://doi.org/10.1159/000079326)
- Franko, D. L., Striegel-Moore, R. H., Thompson, D., Affenito, S. G., Schreiber, G. B., Daniels, S. R., & Crawford, P. B. (2008). The relationship between meal frequency and body mass index in black and white adolescent girls: More is less. *International Journal of Obesity*, 32, 23-29. doi: [10.1038/sj.ijo.0803654](https://doi.org/10.1038/sj.ijo.0803654)
- Friel, A., & Benardot, D. (2011). The relationship between within-day energy balance and menstruation in active females. *Medicine & Science in Sports & Exercise*. 43(5): s68. (Abstract).
- Grages, M. (2013). *National Team Figure Skaters: Poor Energy Balance and Blood Sugar Maintenance Associated with Lower Bone Density and Higher Body Fat*. (Unpublished Master's Thesis). Georgia State University, U.S.A.
- Haase, A. M., Prapavessis, H. & Owens, R. G. (2002). Perfectionism, social physique anxiety and disordered eating: a comparison of male and female elite athletes. *Psychology of Sport and Exercise*, 3(3), 209-222. Retrieved from <http://www.sciencedirect.com/science/article/pii/S1469029201000188?np=y>
- Hall, K. D., Heymsfield, S. B., Kemnitz, J. W., Klein, S., Schoeller, D. A., & Speakman, J. R. (2012). Energy balance and its components: implications for body weight regulation. *The American Journal of Clinical Nutrition*, 95(4), 989-994. doi: [10.3945/ajcn.112.036350](https://doi.org/10.3945/ajcn.112.036350)
- Hawley, J. A. & Burke, L. M. (April, 1997). Effect of meal frequency and physical performance. *British Journal of Nutrition*, 77 (supplement 01), :S91-S103. doi: <http://dx.doi.org/10.1079/BJN19970107>

- Hubbard, R. W., Szlyk, P. C., & Armstrong, L. E. (1990). Influence of thirst and fluid palatability on fluid ingestion during exercise. In C. V. Gisolfi, and D. R. Lamb (Editors). *Fluid Homeostasis During Exercise*. (pp. 39-95).
- Isacco, L., Lazaar, N., Ratel, S., Thivel, D., Aucouturier, J., Doré, E., . . . Duché, P. (2010). The impact of eating habits on anthropometric characteristics in French primary school children. *Child: Care, Health and Development*, 36(6), 835-842. doi: [10.1111/j.1365-2214.2010.01113.x](https://doi.org/10.1111/j.1365-2214.2010.01113.x)
- Iwao, S., Mori, K., & Sato, Y. (1996). Effects of meal frequency on body composition during weight control in boxers. *Scandinavian Journal of Medicine & Science in Sports*, 6(5),265-272. doi: [10.1111/j.1600-0838.1996.tb00469.x](https://doi.org/10.1111/j.1600-0838.1996.tb00469.x)
- Jenkins, D. J., Wolever, T. M., Vuksan, V., Brighenti, F., Cunnane, S. C., Rao, A.V.,. . . Josse, R. (October, 1989). Nibbling versus gorging: metabolic advantages of increased meal frequency. *New England Journal of Medicine*, 321(14), 929-934. doi:[10.1056/NEJM198910053211403](https://doi.org/10.1056/NEJM198910053211403)
- Knerr, I., Gröschl, M., Rascher, W., & Rauh, M. (2003). Endocrine effects of food intake: Insulin, ghrelin, and leptin responses to a single bolus of essential amino acids in humans. *Annals of Nutrition & Metabolism*, 47, 312-313. doi: [10.1159/000072405](https://doi.org/10.1159/000072405)
- Koletzko, B. & Toschke, A. M. (February, 2010). Meal patterns and frequencies: Do they affect body weight in children and adolescents? *Critical Reviews in Food Science*, 50(2), 100-105. doi: [10.1080/10408390903467431](https://doi.org/10.1080/10408390903467431)
- Krane, V., Waldron, J., Stiles-Shipley, J. A. & Michalenok, J. (2001). Relationships among body satisfaction, social physique anxiety, and eating behaviors in female athletes and exercisers. *Journal of Sport Behavior*, 24(3). Accession No. 77384743. Retrieved from <http://www.biomedsearch.com/article/Relationships-Among-Body-Satisfaction-Social/77384743.html>
- Leibel, R. L., Rosenbaum, M. & Hirsch, J. (March, 1995). Changes in energy expenditure resulting from altered body weight. *New England Journal of Medicine*, 332(10), 621-628. doi: [10.1056/NEJM199503093321001](https://doi.org/10.1056/NEJM199503093321001)
- Maughan, R. J. & Noakes, T. D. (1991). Fluid replacement and exercise stress. A brief review of studies on fluid replacement and some guidelines for the athlete. *Sports Medicine*, 12(1), 16-31. Retrieved from: <http://link.springer.com/article/10.2165/00007256-199112010-00003#page-2>
- Melby, C. M. & Hickey, M. (2005). Energy balance and body weight regulation. *Sports Science Exchange*, 18 (4), 1-6. Retrieved from http://www.uni.edu/dolgener/UG_Sport_Nutrition/Articles/Energy_Balance.pdf
- Nieman, D. C., Henson, D. A., Smith, L. L., Utter, A. C., Vinci, D. M., Davis, J. M., & Shute, M. (July, 2001). Cytokine changes after a marathon race. *Journal of Applied Physiology*, 91(1),109–114. Retrieved from <http://jap.physiology.org/content/91/1/109.abstract>
- Paddon-Jones, D, & Rasmussen, B. B. (2009). Dietary protein recommendations and the prevention of sarcopenia. *Current Opinion in Clinical Metabolic Care*, 12(1), 86-90. doi: [10.1097/MCO.0b013e32831cef8b](https://doi.org/10.1097/MCO.0b013e32831cef8b)
- Peiris, A. N., Mueller, R. A., Smith, G. A., Struve, M. F., & Kissebah, A. H. (December, 1986). Splanchnic insulin metabolism in obesity. Influence of body fat distribution. *The Journal of Clinical Investigation*, 78(6), 1648-1657. doi: [10.1172/JCI112758](https://doi.org/10.1172/JCI112758)
- Saad, M. F., Bernaba, B., Hwu, C-M., Jinagouda, S., Fahmi, S., Kogosov, E., & Boyadjian, R. (August, 2002). Insulin regulates plasma ghrelin concentration. *The Journal of Clinical Endocrinology & Metabolism*, 87(8), 3997-4000. doi: [10.1210/jc.87.8.3997](https://doi.org/10.1210/jc.87.8.3997)
- Saltzman, E. & Roberts, S. B. (August, 1995). The role of energy expenditure in regulation: findings from a decade of research. *Nutrition Reviews*, 53(8), 209-220. doi:[10.1111/j.1753-4887.1995.tb01554.x](https://doi.org/10.1111/j.1753-4887.1995.tb01554.x)

- Smith, K., Gall, S., McNaughton, S. A., Blizzard, L., Dwyer, T., & Venn, A. J. (October, 2010). Skipping breakfast: Longitudinal associations with cardiometabolic risk factors in the Childhood Determinants of Adult Health Study. *The American Journal of Clinical Nutrition*, 92, 1316-1325. doi: [10.3945/ajcn.2010.30101](https://doi.org/10.3945/ajcn.2010.30101)
- Solomon, T. P. J., Chambers, E., Jeukendrup, A., Toogood, A. A., & Blannin, A. K. (October, 2008). The effect of feeding frequency on insulin and ghrelin responses in human subjects. *British Journal of Nutrition*, 100(4), 810-819. doi:<http://dx.doi.org/10.1017/S000711450896757X>
- Stafford, D. E. J. (June, 2005). Altered hypothalamic-pituitary-ovarian axis function in young female athletes. *Treatments in Endocrinology*, 4(3): 147-154. Retrieved from <http://link.springer.com/article/10.2165/00024677-200504030-00003>
- Toshinai, K., Mondal, M.S., Nakazato, M., Date, Y., Murakami, N., Kojima, M., . . . Matsukura, S. (March, 2001). Upregulation of ghrelin expression in the stomach upon fasting, insulin-induced hypoglycemia, and leptin administration. *Biochemical and Biophysical Research Communications*, 281(5), 1220-1225. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0006291X01945188?np=y>
- Viskaal-van Dongen, M. V., de Graaf, C., Siedelink, E. & Kok, F. J. (February, 2009). Hidden fat facilitates passive overconsumption. *Journal of Nutrition*, 139(2), 393-399. doi:[10.3945/jn.108.096123](https://doi.org/10.3945/jn.108.096123)
- Vardar, E., Vardar, S. A., & Kurt, C. (April, 2007). Anxiety of young female athletes with disordered eating behaviors. *Eating behaviors*, 8(2), 143-147. Retrieved from <http://www.sciencedirect.com/science/article/pii/S147101530600016X>
- Wing, R. R. & Phelan, S. (July, 2005). Long-term weight loss maintenance. *The American Journal of Clinical Nutrition*, 82 (Suppl.1), 222S-225S. Retrieved from <http://ajcn.nutrition.org/content/82/1/222S.abstract>



Esta obra está bajo una

[licencia Creative Commons Atribución-NoComercial-SinDerivadas 3.0 Costa Rica.](https://creativecommons.org/licenses/by-nc-nd/3.0/cr/)