From Energy Dissipation to Information Density: Metabolic Rate in the Geometry of Aging

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Abstract

We study the relationship between basal metabolic rate and weight throughout life in humans. Our previous work has yielded tables and graphs with specific data. In this article, we discuss its relationship to the geometry of biological systems. We also address its relationship to the holographic description of biological systems in general. This allows us to approach the fundamentals of the aging process through its determinants: the size, shape, and dimension of living beings.

Keywords: basal metabolic rate, relative surface, Bekenstein border, hologram, geometric phase, Margalef principle

1. Introduction

The concept of *velocity* originates from physics and quantifies the distance traveled by an object over a given time interval, formalized as $v = d/t$. By analogy, if the distance traveled is replaced by the energy expended by an organism over a specific period, we obtain its *metabolic rate*.

However, when considering the energy expenditure of an organism (rather than the displacement of an object) over time, the scenario becomes more complex. This complexity arises due to the involvement of numerous additional variables beyond those in mechanical velocity. Below, we analyze the most significant factors.

Living organisms increase their mass and size—they grow—until a certain point in their lifespan (shortly after puberty in humans and other species). Consequently, the energy expended by the organism rises during a significant portion of its lifetime.

The observation that a physical system can dissipate increasing amounts of energy might mistakenly suggest a violation of the **second law of thermodynamics**. Yet, it is unsurprising that an adult human dissipates more total energy than an infant over the same period. Similarly, an elephant weighing 5 tons will inevitably dissipate more energy than a mouse weighing a few dozen grams in the same timeframe.

In both cases, the greater total energy dissipation is due to the system's larger mass. This does not imply a higher *velocity* of metabolic reactions but rather a higher *frequency* of those reactions (due to increased mass) occurring at the same intrinsic rate. Frequency and velocity are distinct concepts.

All physical systems must comply with the **second law of thermodynamics**, and the evolution of energy dissipation in such systems must be expressed consistently with this law.

One way to demonstrate the decline in energy transformation capacity is to express energy dissipation **per unit mass** (preferably dry or water-free mass, if possible) rather than per total system mass. This approach uses metabolically active mass as the reference unit.

Consequently, it becomes apparent that a mouse dissipates more energy per unit mass than an elephant, just as a human infant dissipates more energy per unit mass than an adult of the same species. This framework restores conceptual order.

Only then can a precise definition of **metabolic velocity** be established, as metabolic reactions occur within a given mass—just as distances are traversed over a given time interval.

The analysis of results from prior research by these investigators (Barragán, J. & Sánchez, S., 2022) yields particularly insightful conclusions concerning this issue

When comparing the total BMR/day with the dry BMR/Kg, R^2 has a value of 0.96 ($p < 0.02$), which is statistically significant as can be seen in Figure 1.
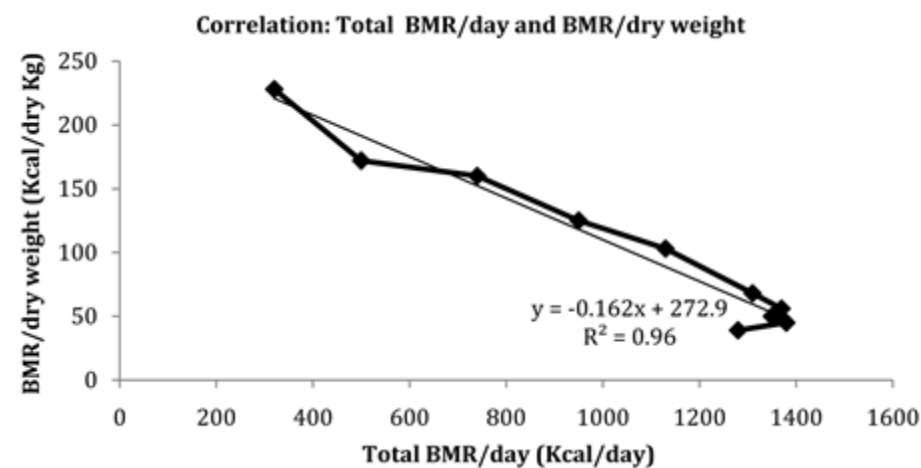

Figure 1. Relationship between total energy dissipation and energy dissipation per body mass unit

But when comparing the total BMR/day with the total body mass, R^2 has a value of 0.84 (NS), showing that there is no statistically significant association, as can be seen in Figure 2.
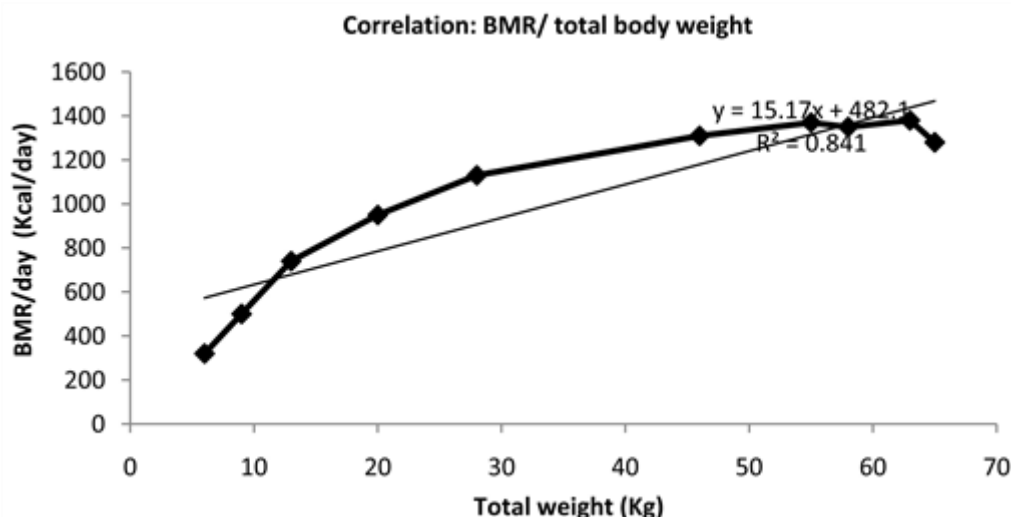

Figure 2. Relationship between total energy dissipation and the total body mass of the organism

These results are nothing more than the formalization of simple reasoning that arises from analyzing Table 1: If 6 kg of total body mass dissipates 320 Kcal/day, it would be expected that 65 kg of total body mass dissipates 3466 Kcal/day. However, that is not what happens. An older

adult, weighing 65 kg, dissipates 1280 Kcal/day.

Table 1.

Age (years)	Total Weight (kg)	Total BMRl/day (Kcal/day)	BMR/kg (Kcal/dry weight)	Dry weight (kg)
0 - 0.5	6	320	228	1.4
0.5 - 1	9	500	172	2.9
1 - 3	13	740	160	4.6
4 - 6	20	950	125	7.6
7 - 10	28	1130	103	10.9
11 - 14	46	1310	68	19.3
15 - 18	55	1370	56	24.2
19 - 24	58	1350	50	26.6
25 - 50	63	1380	45	30.2
51 or more	65	1280	39	32.5

Table 1 shows total weight values, total kcal dissipated per day, and BMR/dry kg for different ages. Sample demographic characteristics: Argentine population white (Hispanic) race. Sample size: n = 10,960.

If instead, we observe the BMR/dry kg (fourth column) and the dry weight (fifth column) for each age, the following can be seen: A newborn whose dry BMR/kg is 228 Kcal and whose dry weight is 1.4 kg, dissipates 319.2 Kcal. An older adult, weighing 65 kg, whose BMR/dry kg is 39 Kcal and whose dry weight is 32.5 kg, dissipates 1267 Kcal/day. That is exactly what happens: a newborn dissipates 320 Kcal/day, and an older adult 1280 Kcal/day (third column of Table 1).

2. A Logical Equivalence

Continuing with the reasoning, if a tiny baby dissipates energy at a certain rate, and as it grows (increasing its mass) that rate decreases, then we have a metabolic acceleration. A negative acceleration.

In previous studies, the authors worked on this logical equivalence between mechanical velocity and metabolic velocity, as well as between mechanical acceleration and metabolic acceleration.

Of course, we are not proposing a physical equivalence between the two velocities, because we know they measure different variables and properties. But both concepts have the same truth value and the same rate of change. Their formalizations reveal the logical equivalence between the two.

It is important to know that we have metabolically accelerated systems. And to understand the origin of acceleration, we must analyze the calculation of energy dissipation in a biological physical system.

Another publication by the authors should be cited here to understand the problem. (Barragán, J. & Sánchez, S., 2023)

From the thermodynamic point of view, in a unicellular system we can calculate the total energy dissipated as the sum of the dissipations that occur in the system, in a similar way to the calculation of the linear momentum in an inertial system when we study mechanics (no fictitious forces are involved). (Ciufolini, I., 2007)

When analyzing the dissipation of energy, we will see that the system dissipates less and less energy (second law of thermodynamics), but it does so constantly generation after generation. Its increase in mass does not exceed the range of unity and the dissipation of energy per unit of mass is equal to the total dissipation of the system.

Yet when we study a complex system, the situation is different. The system dissipates more and more energy until it reaches its maximum complexity and also increases its mass above the value of unity. (Østbye, T., Malhotra, R. & Landerman, L.R., 2011; West, G.B. & Brown, J.H., 2004) What are the possible interpretations of this situation?

Serious thought should be given to the meaning of this question. In a complex biological system, self-organization operates as a fictitious force, which can be seen in the increase in mass of the system and in the apparent increase in its energy dissipation capacity. Self-organization operates as a particular force of aggregation of matter, which leads to the increasing ordering of it. (Isaeva, V.V., 2012; Wedlich-Söldner, R. & Betz, T. 2018; Ivanitskii, G.R., 2017)

Thus, the calculation of the total energy dissipated by the system does not depend only on the energy dissipated per unit of mass, but the intervention of the fictitious force of self-organization must be considered. It is a situation similar to that of non-inertial systems when we study mechanics (fictitious forces intervene when we calculate the linear momentum of the system). (Kamalov, T.F., 2010)

This implies that the decline in energy dissipation per unit mass in complex multicellular living things is not due to the second law of thermodynamics alone. The action of the self-organization force must also be considered.

The decline in energy dissipation per unit mass is not constant in the case of a complex multicellular organism. It behaves like a negative "metabolic acceleration" and because it is an accelerated system it turns out to be equivalent to what in mechanics is a non-inertial system. (Kamalov, T.F., 2010)

As demonstrated previously, the fundamental correspondence between mechanical and metabolic velocity metrics reduces to: (Barragán, J. & Sánchez, S., 2024; Barragán, J. & Sánchez, S., 2025)

We formalize the metabolic acceleration as Ma = BMR/m², where Ma is the metabolic acceleration; BMR is the energy dissipated, expressed in kcal per unit of mass $\frac{kcal}{m}$ and m is the mass expressed in kg of weight.

So the metabolic acceleration is $Ma = \frac{\frac{kcal}{m}}{m} = \frac{kcal}{m^2}$.

We formalize the mechanical acceleration as $A = \frac{d}{t^2}$ where A is the mechanical acceleration; d is the distance traveled per unit of time, expressed in meters per second; and t is the time expressed in seconds.

As the speed is $v = \frac{d}{t}$ where d is the distance

expressed in meters and t is the time expressed in seconds.

Therefore, the mechanical acceleration is $A = \frac{\frac{m}{s}}{s} = \frac{m}{s^2}$.

We define this logical equivalence as

$$\frac{BMR}{m^2} : \Leftrightarrow \frac{d}{t^2}$$

3. When Do We Start to Age?

We define aging as the gradual loss of self-organization and homeostatic capacity. To understand how, when, and why aging occurs, we must first revisit the fundamentals of biological self-organization and homeostasis.

Living organisms are complex physical systems comprising: (Margalef, R., 2002; Margalef, R., 1995)

1) An energy-dissipating system, coupled with

2) A complementary energy-to-information recovery system

This dual architecture enables organisms to:

• Self-organize by generating structure from dissipated energy

• Maintain structural identity (homeostasis) despite perturbations

3.1 The Geometry of Biological Order

A system's tendency toward order depends on its geometry, which is determined by its information density. Since information (embodied in the system's material structure) is recovered from dissipated energy, a crucial relationship emerges both energy dissipation and information correlate more strongly with surface area than with volume. (Bigatti, D. & Susskind, L., 2000)

This reflects the **holographic principle**: within any bounded spatial region, entropy (a measure of system information) scales with surface area rather than volume.

3.2 The Information Density Limit

As organisms dissipate energy, they accumulate information. However, their finite surface area imposes a fundamental limit on recoverable information density. This creates an intimate energy-information relationship where: (Bekenstein, J., 2003)

1) Growth occurs through information accumulation from dissipated energy

2) Growth simultaneously reduces surface-to-volume ratio

Consequently:

- Energy dissipation capacity declines with size (being surface-dependent)

- Information density approaches its theoretical maximum (the Bekenstein bound)

This limit, formally described by Jacob Bekenstein, defines the conditions where a spatial region gains a new degree of freedom upon reaching maximum information density - effectively causing an n-dimensional space to exhibit (n+1)-dimensional properties at the boundary. (Bekenstein, J., 2003)

3.3 Critical Distinctions

Proper understanding requires careful differentiation between:

- Absolute size vs. dimensional scaling

- Information content vs. information density

- Surface-mediated processes vs. volumetric constraints

4. Size and Dimension in Biological Systems

4.1 Fundamental Definitions

- **Size**: The spatial extension of a material object, quantifiable as length (1D), area (2D), or volume (3D). Size represents magnitude without inherent reference to dimensionality.

- **Dimension**: The number of linearly independent basis vectors in a given space. Exemplified by:
    - Line (1D)
    - Plane (2D)
    - Volume (3D)

4.2 Key Distinction

Two circles differing in area possess distinct sizes but identical dimensionality (both being 2D planar figures). This separation becomes evident through surface curvature:

Illustrative Example:

A triangle drawn on:

1) A deflated balloon (2D planar surface)

2) The same balloon when inflated (3D curved surface)

While the triangle's size (edge lengths) remains constant, its embedding dimension increases from 2 to 3 through surface curvature.

4.3 Biological Implications

When an organism survives its growth phase boundary:

1) It reaches its **information density limit** (Bekenstein bound)

2) Its parameter space maintains size but gains dimensionality (+1 degree of freedom)

3) Energy-to-information recovery continues in this curved geometry

4.4 The Aging Mechanism

This dimensional transition induces:

- Progressive failure of variables to return to baseline values (geometric phase shift) (Barragán, J. & Sánchez, S., 2023)

- Declining system efficiency

- Emergence of aging as a geometric phenomenon

5. The Geometric Foundations of Biological Shape

The seminal question "Why is animal size so important?" posed by Knut Schmidt-Nielsen revolutionized biological thinking. The Norwegian naturalist's pioneering work established the fundamental relationship between organismal size and energy dissipation – perhaps his most enduring scientific legacy. (Schmidt-Nielsen, Knut, 1984)

5.1 Shifting the Paradigm to Shape

While understanding the determinants of biological morphology remains crucial, our focus centers on the tripartite relationship between *shape*, *size*, and *dimension*. Consider human embryogenesis: (Barragán, J. & Sánchez, S. 2023; Kaneko, K.J., 2016; Watanabe, T., Biggins, J.S., Tannan, N.B. & Srinivas, S., 2014)

1) **Week 1**: Spherical zygote (isotropic geometry)

2) **Week 2**: Bilaminar disc (planar topology)

3) **Week 4**: Cylindrical structure (neutral curvature)

This developmental trajectory - conserved across multicellular organisms — reveals a profound geometric principle: *Order emerges when system variables occupy spaces with*: (Solis Gamboa, D.A., 2010)

- Positive curvature (sphere)

- Null curvature (plane)

- Neutral curvature (cylinder)

5.2 Post-Growth Phase Transition

Upon reaching puberty's information density limit:

- Size stabilization occurs

- Dimensionality increases (+1 degree of freedom)

- Geometric phase shift manifests

Though macroscopic morphology remains apparently cylindrical, the system now operates in higher-dimensional space. (Jorge Barragán & Sebastián Sánchez, 2023)

This transition becomes detectable only through:

1) Aging-related variable drift

2) Progressive loss of homeostatic precision

The curvature of this emergent dimension presents detection difficulties analogous to temporal dimensions in spacetime - neither more nor less tractable than relativistic geometry. The aging process itself becomes the observable signature of this dimensional transformation. (Weisstein, E.W., 2024; Einstein, A., 1916; Thaheld, F.H., 2005)

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