

# About the Thermodynamics and Aging of Self-Organizing Systems

Jorge Barragán, Sebastián Sánchez

Department of Histology, Universidad del Gran Rosario, Rosario, Argentina

Email: barraganjorge49@gmail.com

**How to cite this paper:** Barragán, J. and Sánchez, S. (2023) About the Thermodynamics and Aging of Self-Organizing Systems. *Advances in Aging Research*, 12, 56-66.

<https://doi.org/10.4236/aar.2023.124005>

**Received:** April 28, 2023

**Accepted:** June 30, 2023

**Published:** July 3, 2023

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## Abstract

We know that the total daily energy dissipation increases in complex organisms like the humans. It's very probable that this increase in total energy dissipation is related to the progressive increase in mass. But we also know that day by day the dissipation of energy per unit mass decreases in these organisms. We intend to verify if this decrease is only an expression of the second law of thermodynamics, or if it is related to the increase in mass that occurs in these organisms. For this, we set ourselves the following objectives: verify the correlation between total energy dissipation and the evolution of body mass, and verify the correlation between the dissipation of energy per unit of mass and the evolution of body mass. As a result of the data analysis, we found a high degree of correlation between total energy dissipation and the evolution of body mass. And we also found a high correlation between the energy dissipated per unit of mass and the evolution of body mass. We can conclude that self-organization produces not only an increase in mass, but also a decline in energy dissipation per unit mass beyond what is expected by the second law of thermodynamics.

## Keywords

Body Mass, Energy Dissipation, Neutral Operator, Structural Geometry, Information Density, Inertial Systems, Non-Inertial Systems

## 1. Introduction

Human beings, like all living beings, can be defined as complex physical systems, made up of a system that dissipates energy associated with a self-organizing system that recovers the dissipated energy as information. This means that the dissipated energy is used to generate the very structure of the living being (the set of relationships between the material elements that constitute it). Thus, the set of

variables that make up the system defines their values in a limited and specific spatial region. [1] [2]

It is essential to highlight that the spatial region in which the values of the variables are defined is always the same. For example, the heart rate is always defined in a specific part of the system. [3] Although the system moves in relation to a certain reference system, it does not suffer displacements within the region in which its variables are defined (the system cannot move with respect to itself). The spatial region in which the system is defined can grow in size or stop growing, but it is always within the same region.

And since the geometry of the system is of particular importance to understand its evolution, [4] we must pay attention to the role of time as an operator within the spatial region in which the system variables are defined. Time passes within the region in the same way as in the local environment of the region. But since it is the same for each point in the space where the system variables are defined, there are no relative temporal differences between its parts. So time turns out to act like a neutral operator within the region.

Bearing in mind that a system tends to order when its geometry presents curvature that is null (a flat surface), neutral (the surface of a cylinder), or positive and of equal value at all its points (the surface of a sphere), [5] [6] [7] the evolution of time has the same effect as the latter case: it operates in the same way and with the same value at all points in the system. Thus, regarding the tendency to order the system, it acts as a neutral operator (although it does not strictly comply with the mathematical definition of a neutral operator).

The case is similar to the passage of time on Earth. A day of time elapsed in Berlin is 24 hours, the same as in Tokyo or Moscow. So after one day, two days or many days have elapsed, the relative time differences (the number-of-hour time difference) between Berlin, Tokyo and Moscow will remain the same. Elapsed time does not modify the relative temporal differences within the spatial region in which a system is defined and therefore acts like a neutral operator.

When growth ceases shortly after puberty, life continues in a space that no longer grows and in which time is a neutral operator. This means that the system continues to generate its own material structure in a space that no longer grows. [4] As a result, the information density increases (there is more and more information in the same space), until reaching the information density limit [3] for that spatial region.

By having more and more information (more material structure) in a space that no longer grows, the space curves in the region where the system variables are defined. This is seen as a phase shift in the oscillations of the variables, which is due to the change in the geometry of the system when growth ceases. [4] This phenomenon (and nothing else) causes the transition to disorder and the gradual loss of homeostasis that characterizes the aging process.

At this point in the theoretical framework, it is convenient to distinguish two major possible situations. One is that of the simplest living beings, the unicellular ones, in which the minimum unit of life is in turn the entire system. The oth-

er case is that of the most complex living beings, in which the smallest unit of life is subsumed in a more complex system. [8] [9] This is important because aging and its thermodynamic characteristics will look different in each case.

A more complex living being is larger and more massive than a simple unicellular being. If we estimate the mass as weight and consider the kg as a unit, a unicellular organism is comparable to the unit of mass (regardless of its mass), since its size is included within the value of the unit of mass. The most complex living beings can, on the other hand, increase many times the value of the unit of mass and weigh much more than a unicellular organism. [10] [11]

At the same time, this is related to the energy dissipation capacity in a more complex (multicellular) system. The total energy dissipated by the system increases, but the energy dissipated per unit of mass decreases. [3] It is important to verify if the decrease in energy dissipation per unit of mass is related to the increase in total mass (a mass effect produced by self-organization), or is just the simple expression of the second law of thermodynamics.

Our objectives are:

- 1) Verify in human beings the correlation between the evolution of body mass (assessed as total body weight and as dry or body weight free of water) and the dissipation of energy per unit of mass (dry or free of water) throughout life.
- 2) Evaluate in human beings the correlation between the evolution of body mass (as total body weight and as dry or water-free body weight) and total energy dissipation per day throughout life.

The consideration of dry weight avoids some distortions of the results in the first years of life, and since water is a product of the metabolic activity, the use of dry kg as a unit of mass introduces a corrective factor that increases the precision of the study. [12]

## 2. Material and Methods

Human body weight values for different ages were studied and expressed in kg, both for total body weight and dry weight (free of water).

To analyze energy dissipation, the basal metabolic rate (BMR) per day for total body mass, as well as the BMR per kg dry weight, was studied. The values were expressed in Kcal/day and Kcal/Kg dry respectively.

Such values of evolution of body weight and energy dissipation throughout the life of a human being are summarized in **Table 1**.

The BMR/kg dry data (third column) were compared with the dry body weight data (second column) applying a correlation test or coefficient of determination R<sup>2</sup>. The same procedure was applied to compare the data for BMR/kg dry (third column) with that for total body weight (fourth column).

Data for total BMR per day (fifth column) were also compared with data for total body weight (fourth column), applying a correlation test or coefficient of determination R<sup>2</sup>. The same procedure was applied to compare the data of the total BMR per day (fifth column) with those of dry weight (second column).

**Table 1.** It shows the values of age, mass and energy dissipation in humans of both sexes. Sample demographic characteristics: Argentine population (white race). Sample size: n = 9600.

Age (years)	Dry weight (kg)	BMR/kg (Kcal/dry weight)	Total Weight (kg)	Total BMR/day (Kcal/day)
0 - 0.5	1.4	228	6	320
0.5 - 1	2.9	172	9	500
1 - 3	4.6	160	13	740
4 - 6	7.6	125	20	950
7 - 10	10.9	103	28	1130
11 - 14	18.0	80	45	1440
15 - 18	27.7	63	66	1745
19 - 24	30.9	57	72	1761
25 - 50	34.7	51	79	1769
51 or more	34.6	44	77	1522

### 3. Results

The correlation between the evolution of the BMR/kg dry and the evolution of the body dry weight (third and second columns of **Table 1**) presents a result  $R^2 = 0.8579$  ( $p < 0.05$ ) and is observed in **Figure 1**.

The correlation between the evolution of the BMR/kg dry and the evolution of the total body weight (third and fourth columns of **Table 1**) presents a result  $R^2 = 0.8541$  ( $p < 0.05$ ), and is observed in **Figure 2**.

The correlation between the evolution of the BMR/day and the evolution of the dry body weight (fifth and second columns of **Table 1**) presents a result  $R^2 = 0.9123$  ( $p < 0.02$ ) and is observed in **Figure 3**.

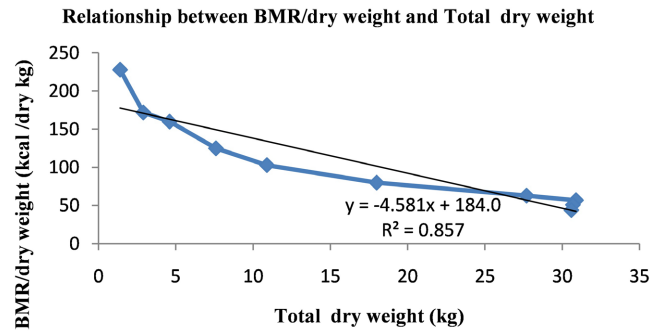
The correlation between the evolution of the BMR/day and the evolution of the total body weight (fifth and fourth columns of **Table 1**) presents a result  $R^2 = 0.8975$  ( $p < 0.05$ ), and is observed in **Figure 4**.

All the studied correlations were statistically significant, evidencing the strong association between the increase in body mass and the increase in total energy dissipation per day.

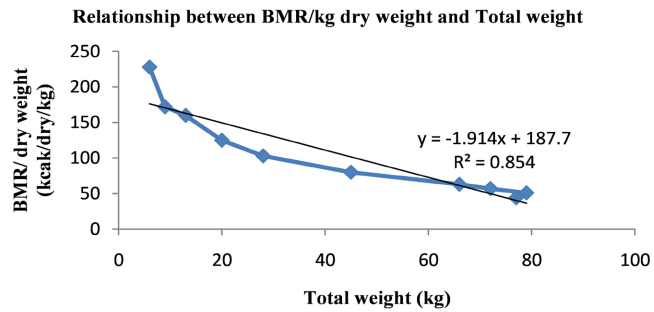
Similarly, the results show a significant association between the increase in body mass and the reduction in energy dissipation per unit of mass.

### 4. Discussion

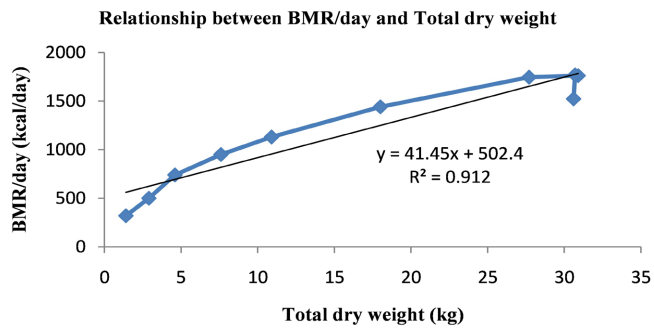
From the thermodynamic point of view, in a unicellular system we can calculate the total energy dissipated as the sum of the dissipations that occur in the system, in a similar way to the calculation of the linear momentum in an inertial system when we study mechanics (no fictitious forces are involved). [13] 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



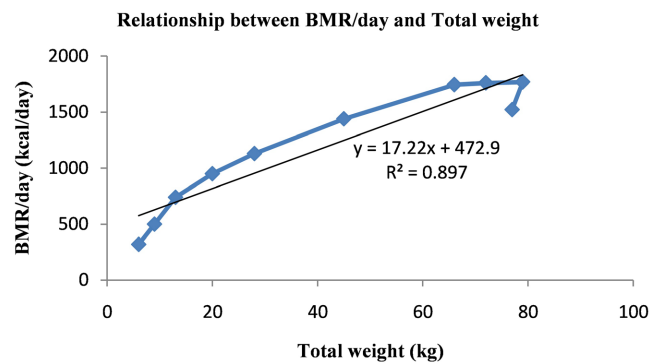
**Figure 1.** Correlation between BMR/dry weight and total dry weight. Sample size: n = 9600.



**Figure 2.** Correlation between BMR/kg dry weight and total weight. Sample size: n = 9600.



**Figure 3.** Correlation between BMR/day and total dry weight. Sample size: n = 9600.



**Figure 4.** Correlation between BMR/day and total weight. Sample size: n = 9600.

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. [10] [11] What are the possible interpretations of this situation?

A direct and linear interpretation is to consider that if the system evolves effectively dissipating more and more energy, it is evident that it does not comply with the second law of thermodynamics. But in reality it is a wrong reasoning, because if we analyze the evolution of the dissipation of energy per unit of mass, we will see that it declines. [3] [12] The system is complying with the second law of thermodynamics. We did not expect anything else. But what does this analysis mean?

The increase in the energy dissipation capacity of the system is only apparent (fictitious), since it is due to the increase in the total mass of the system. But it is clear that when analyzing the dissipation per unit mass, it can be seen that the system complies with the second law of thermodynamics.

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. [14] [15] [16]

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). [17]

No one is surprised by the simple example of the elevator in free fall. Its occupants stop feeling their own weight and believe they are floating in the elevator. Even if he were a waiter, he would see the tray with the coffee cups floating. It is the reference system (the elevator) that is in free fall. But since the waiter travels within the frame of reference, even if he doesn't notice it, he is also falling (he will realize it when he reaches the floor along with the elevator).

In the same way, a complex living being observes (like a human) that it dissipates more and more energy, as if it did not feel the effect of the second law of thermodynamics ("he is floating in an elevator in free fall"). But when it reaches its greatest complexity and ceases to grow, it will notice that its abilities to dissipate energy and self-organize declines (he begins to realize that "he is falling with the elevator"). 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. However, aging is not due to the fact that we dissipate less and less energy per unit of mass (until puberty we make more and more organized mass

with less and less energy dissipated per unit of mass). Aging begins when growth ends, because the information density increases and modifies the geometry of the system.

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. [17] On the other hand, in the case of a unicellular organism, the decline in energy dissipation per unit mass is constant (without metabolic acceleration) and is caused exclusively by the second law of thermodynamics (the fictitious force of self-organization does not intervene beyond the value of the unit of mass).

If the decline in energy dissipation were to increase with each division of the unicellular organism, after a few generations the energy dissipation capacity would not be sufficient to support life processes. But single cells are still there, because the decline in power dissipation is constant generation after generation. In addition, a unicellular has little information regarding a multicellular and aging will not be noticeable. Only cell death or reproduction will be the indicator of the loss of self-organization capacity and homeostasis that lead the system to lose its identity. [18] [19] [20]

The authors believe that two more considerations are necessary regarding the concept of time as a neutral operator: one of them is that if the passage of time does not modify the relative temporal differences between the variables of the system, then it cannot be the cause of the Chrono disruption that occurs in aging. Said Chrono disruption is due to the changes that occur in the geometry of the system when growth ceases and it reaches its limit of density information. [3] [4] [5]

The other consideration is that if the biological activity (by cryopreservation) [21] [22] [23] [24] of a human being of a certain age (suppose 20 years old) is suspended on a certain specific calendar date, and after 50 years have elapsed we return it to its usual biological activity, we will have a very particular case: since time act like a neutral operator, we will have a 70-year-old human being who looks like a 20-year-old. How old is he really?

The 50 years passed for both the cryopreserved system and its local environment. But since life was suspended in the cryopreserved system, you allow yourself to intuit that he is actually the 20-year-old as he was before his cryopreservation.

You must abandon that intuition and base your answer with concrete data and a rational observation of the situation. Time act like a neutral operator and the only thing that matters is the course of life as an independent vector. The phase shift in the oscillatory variables that occurs at the end of growth is due to a change in the geometry of the system when it reaches its information density limit.

Like in this case, the geometry of the system has not changed since the cryopreservation took place (because the biological processes stopped or were re-

duced to the minimum possible), it is logical that when the system recovers its usual biological activity it looks the same as before cryopreservation (20 years of age).

It is also logical to think that he is 70 years old even though he looks like he is 20 years old, because the 50 years that he was cryopreserved passed effectively and the same occurred with the cryopreserved system for his local environment. The level of cold used for cryopreservation stops metabolic and biological cycles (the metric of life), but it does not stop the passage of time (the metric of time).

What is not logical is to measure life in terms of years elapsed. This situation reveals itself, because the biological phenomenon is self-referred regardless of the course of time. There are many theories of aging and all correctly describe the phenomenon, from genetics to caloric restriction. From our proposal we observe that caloric restriction limits energy dissipation. But since the dissipated energy is used to generate structure, then its generation will be limited. The metabolism slows down and the organism “lives longer timer” but “doesn’t live more.” It just does the same thing it always does, but slower and therefore spends more time doing it. If we keep in mind that the biological phenomenon is self-referred and does not depend on time (the case of cryopreservation is clear in this regard), then prolonging life time is not the same as prolonging life..

The concept that **Figure 1** and **Figure 2** express are about the relationship between the kcal dissipated per unit of mass and the mass of the living being, summarizes the idea of metabolic acceleration caused by self-organization and can be formalized as follows:

$$SOa = \frac{\frac{kcal}{m}}{m} = \frac{kcal}{m^2}$$

whereas  $SOa$  is the metabolic acceleration due to self-organization and  $m^2$  is the squared value of the mass. This is obviously a negative acceleration. Since each species and type of organism has its own values of energy dissipation and evolution of its mass, it is likely that the  $SOa$  value is a particular value for each species and type of organism (like the metric of life). Self-organization turns out to be a force directly proportional to the energy dissipated by an organism, and inversely proportional to the square of its mass.

While this phenomenon of metabolic acceleration occurs in a space of increasing size, its planarity is maintained (it does not curve), because there is more and more material structure (more mass) in more and more space. But when it stops growing and continues to generate more material structure (continuously changing its mass) in the same space, it reaches the limit of information density and causes the spatial curvature that can be seen in the phase shift of its oscillating variables. This is what we appreciate as aging and Chrono disruption [25] [26] [27] is one of the most notable features. The desire to gain an understanding of the aging process and achieve healthy and active aging unites us all. It is necessary to see that the path that leads us to this is marked by the contribution of biology and other disciplines that are beyond it (physics, mathemat-



ics, geometry). Finally, any effort to prolong our useful life will have favorable results if it manages to improve the efficiency to recover dissipated energy as information: we can't avoid aging, but we can age better.

## 5. Conclusions

The objectives of verifying the correlation between the evolution of body mass, total energy dissipation, and per unit of mass can be considered fulfilled.

A high correlation was verified between the evolution of body mass free of water and the dissipation of energy per unit of mass. In the same way, a strong correlation was also verified between the evolution of the total body mass and the dissipation of energy per unit of mass.

An important correlation was also verified between the evolution of body mass free of water and the total daily energy dissipation. Similarly, a strong association was found between the evolution of total body mass and total daily energy dissipation.

This allows us to propose that self-organization, which operates as an aggregation force that orders matter, is a fictitious force that causes an acceleration in the decline of energy dissipation per unit mass in complex living beings.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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