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P1 5 Social Thermoregulation in Capybaras

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Abstract

In cold conditions capybaras often gather closely with one another, forming tight groups to conserve warmth. In this paper, we model the thermal advantage of capybara huddling using Newtonian cooling. We show analytically that heat loss per animal is proportional to the inverse square root of group size. Subsequently, we determine that the cooling time of capybaras in a huddle increases proportionately to the square root of the group size. This indicates that group behaviour is an energetically efficient thermoregulatory mechanism.

Introduction

Capybaras (*Hydrochoerus hydrochaeris*) are highly social mammals known to form close physical groups, often huddling in cool conditions. Although this behaviour is usually described as social bonding, it also serves a thermoregulatory purpose [1]. Like all endotherms, capybaras lose heat to their surroundings primarily through convection and radiation; and the rate of this heat loss depends on body surface area exposed to the environment. Huddling reduces this exposed surface area by bringing warm bodies into contact [2]. This raises the question: Does huddling significantly reduce heat loss in capybaras? In this paper, we develop a simple thermodynamic model using Newton's law of cooling to compare heat loss rates for solitary and huddling capybaras.

Modelling the Capybaras

In order to analyse heat loss quantitatively, we first need a geometric model for a capybara. A vertical cylinder is used to model a capybara throughout the paper. For a single capybara, the area of the top section of their body exposed to the environment, $A_{top,single}$, can be modelled as a circle with radius, r:

$$A_{top,single} = \pi r^2. \tag{1}$$

For a group of capybaras, the area of the top section of their bodies exposed to the environment, $A_{top,group}$, can be modelled as a circle with radius, R:

$$A_{top,group} = \pi R^2. \tag{2}$$

Equations 1 and 2 can be equated by introducing N, the number of capybaras in a huddle:

$$R = r\sqrt{N}. \tag{3}$$

The lateral exposed area, A_{lat}, of a group can be modelled by multiplying the perimeter of the huddle by the height, h, of the capybaras:

$$A_{lat} = 2\pi Rh = 2\pi rh\sqrt{N}. \tag{4}$$

Therefore the total exposed area, A_{tot}, can be expressed as the sum of the topside exposed area and the lateral exposed area:

$$A_{tot} = \pi r^2 N + 2\pi rh\sqrt{N}. \tag{5}$$

Finally, the area exposed of each individual capybara, A_{per}, can be calculated:

$$A_{per} = \frac{A_{tot}}{N} = \frac{2\pi rh}{\sqrt{N}} + \pi r^2. \quad (6)$$

Newton's Law of Cooling

Newton's law of cooling describes how the temperature of an object changes over time when it is exposed to a surrounding environment at a different temperature; and can be expressed by the following equation [3]:

$$Q = h_c A_{per}(T - T_{env}), \quad (7)$$

where Q is the heat flow rate, h_c is the heat transfer coefficient, T is the body surface temperature and T_{env} is the temperature of the environment. Note that this is a simplified version of Newton's cooling equation where h_c is constant. By substituting Equation 6 into Equation 7, it is made apparent that the heat flow rate is proportional to the inverse square root of the number of capybaras in a huddle:

$$Q = h_c(\frac{2\pi rh}{\sqrt{N}} + \pi r^2)(T - T_{env}). \quad (8)$$

This means that as the number of capybaras in a huddle increases, the rate of heat transfer out of the system decreases. Thus capybaras are able to preserve energy by huddling.

Time Taken to Cool

While the previous model shows how huddling reduces energy loss, it does not show how huddling affects cooling speed. Equation 7 is an ordinary differential equation; and solving this results in the time-dependent form of Newton's law of cooling [4]:

$$T = T_{env} + (T_0 - T_{env})e^{\frac{-t}{\tau}}, \quad (9)$$

where T_0 is the initial temperature of the system, t is the time passed since cooling began and τ is the time constant, with units s. The time constant is the most important term in this model because it determines how quickly a capybara cools, and crucially, it can be expressed in terms of exposed area:

$$\tau = \frac{C}{h_c A_{per}}, \quad (10)$$

where C is the specific heat capacity. Since exposed area depends on huddle size, as demonstrated in Equation 6, the time constant allows us to directly link cooling behaviour to group size. The time constant is proportional to the square root of the number of capybaras:

$$\tau = \frac{C}{h_c}(\frac{\sqrt{N}}{2\pi rh} + \frac{1}{\pi r^2}); \quad (11)$$

so as the number of capybaras increases, the cooling time for each capybara increases. Figure 1 demonstrates graphically that capybaras are able to maintain warmth by huddling.

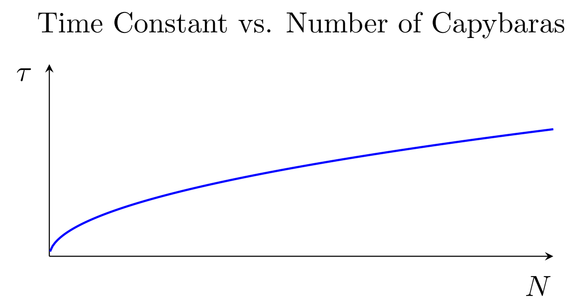

Figure 1: As the number of capybaras in a huddle increases, each individual cools more slowly, with the cooling time rising in proportion to the square root of the group size.

Discussion and Conclusion

While this analysis relies on several simplifying assumptions, such as modelling capybaras as cylinders and assuming that huddles are perfectly compact circles, the overall trend remains the same. As the number of capybaras in a huddle increases, rate of heat transfer out of the system decreases. Analysing this further reveals that as group size increases, and energy loss decreases, the time taken for each capybara to cool increases. This demonstrates that huddling is an effective strategy for capybaras to conserve heat and maintain body warmth.

References

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