NATIONAL CENTER FOR CASE STUDY TEACHING IN SCIENCE

Do Grasshoppers Sweat?

A Surprising Case of Evaporative Cooling

by

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Part I – How Animals Stay Cool

Dr. Henry Prange had just finished giving a lecture on desert animals to his animal physiology class. A particularly inquisitive student stayed after class to discuss various cooling mechanisms, and their conversation centered on interesting behavioral mechanisms employed by desert mammal species. Even after the conversation was over, Dr. Prange kept returning to the question of how animals determine whether they are too hot or too cold.

Dr. Prange designed an experiment to study the behavioral response to different temperature stimuli in a species of mammal. He elected to use mice, as they are common in the physiology lab. He built an "alternative chamber" in which each side was filled with a warmer or cooler temperature than he thought the mouse would prefer. To quantify this, he decided to observe and record the amount of time a mouse would spend in either chamber. Excited and eager to begin his research, Dr. Prange wrote up his scientific experiment and presented it to the head of the physiology lab department.

Questions

1. Give two examples of behavioral adaptations animals could use to keep cool under heat stress.

2. Give two examples of physiological adaptations animals could use to keep cool.

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Part II – A Little Background

Water is obviously very important to life. One example of how organisms can utilize water to survive is *evaporative cooling*. Evaporative cooling lowers an organism's body temperature through the evaporation of water from respiratory or external surfaces. The fastest-moving water molecules (those with the greatest kinetic energy) gain enough energy to leave a surface. This lowers the average kinetic energy of those water molecules left behind, and in turn lowers temperature. Evaporative cooling is particularly important in large animals (organisms with relatively large volumes relative to small surface areas). Additionally, evaporative cooling increases the relative humidity of an environment, due to increasing the level of water vapor present.

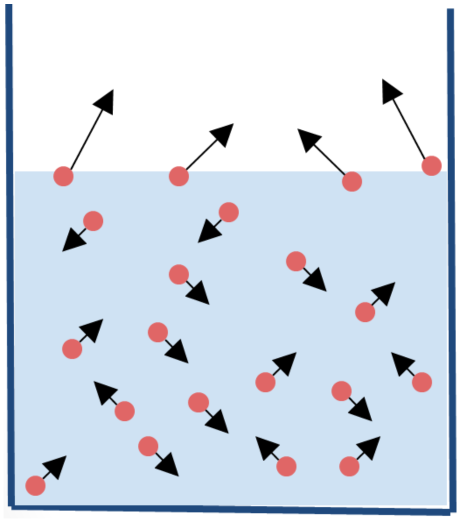


Figure 1. During evaporation, more energetic molecules escape, leaving less energetic molecules behind.

Questions

3. Evaporative cooling, like many biological adaptations, is an emergent property stemming from the basic chemical properties of molecules. Explain some properties of water that allow for evaporative cooling to take place.

4. Evaporative cooling is a product of evolution that has evolved in some organisms for use under certain environmental conditions. Circle the organisms or conditions below that you think are most likely to use evaporative cooling.

Large body size	*Small body size*
Terrestrial organisms	*Flying organisms*
Warm climate	*Cool climate*
Water sources scarce	*Water sources plentiful*

Part III – How Grasshoppers Stay Cool

Unfortunately, Dr. Prange's experiment was rejected. The physiology department had already committed resources to working with specific strains of lab mice; it did not want to risk the chance of contamination with any wild type species. Dr. Prange did not want to give up on his experiment, so he suggested to the physiology department that he use grasshoppers instead. Grasshoppers were readily available, easily bred in captivity, and Dr. Prange saw this as the path of least resistance. The department approved, and Dr. Prange began his experiment on behavioral temperature regulation in the *Schistocerca nitens* species of grasshopper.

Prior to Dr. Prange's experiment, scientists held the belief that, because of their small body size and limited water reserves, grasshoppers (i.e., quiescent insects) were incapable of using evaporative cooling to regulate their body temperature. It was assumed that insects would exclusively rely on behavioral adaptations to keep cool. This phenomenon was well documented and observed.

To begin his experiment, Dr. Prange placed a grasshopper in the warm side of the alternative chamber, which was set to maintain a temperature of around 50 °C. This temperature was generally held to be lethal to an insect. Dr. Prange started the timer and began documenting the grasshopper's behavior. After more than a half hour, he noted that the grasshopper had not moved or shown signs of distress; he assumed it was dead. Dr. Prange reached into the chamber to retrieve the grasshopper, and to his great surprise, it jumped away. Dr. Prange hypothesized that either the grasshoppers had an unusual tolerance for heat, or they were utilizing a cooling mechanism.

Questions

5. From the data acquired in Prange's experiment (Figure 2), determine the temperature that leads to a significant difference between body temperature and air temperature (i.e., greater than about 2 °C difference).

6. As Dr. Prange suggested, the grasshoppers appear to be using some other cooling mechanism(s) besides behavior. Give two examples of cooling mechanisms that grasshoppers in the study might be using.

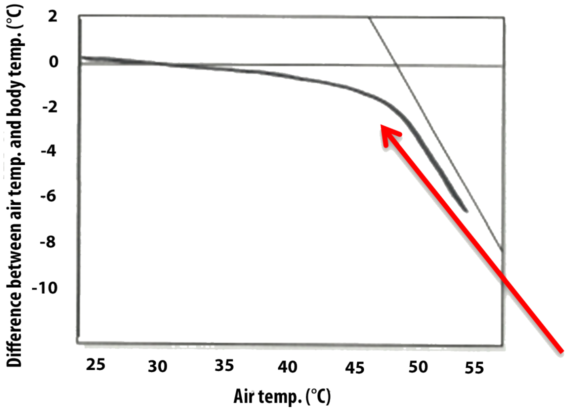


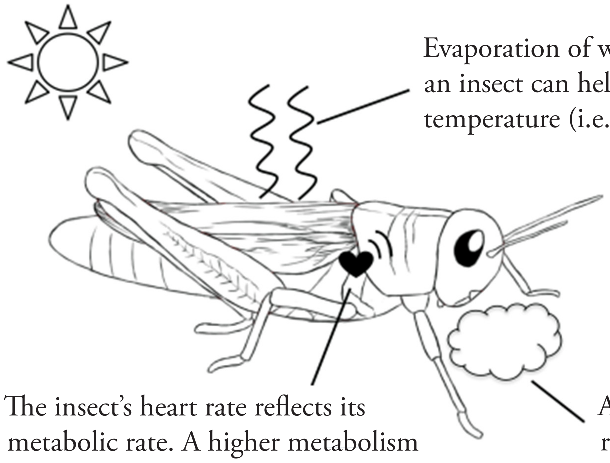
Figure 2. Significant difference between body and air temperature in grasshoppers. Adapted from Prange (1990).

Part IV – What's Going On Here?

Dr. Prange decided to take this experiment a step further. He wanted to know mechanistically how the grasshoppers were able to keep their body temperatures low enough to withstand lethal environmental temperatures. He developed these two hypotheses:

Hypothesis 1: The grasshoppers reduce their body temperature by decreasing their metabolism.

Hypothesis 2: The grasshoppers reduce their body temperature by using an evaporative cooling mechanism.



Evaporation of water from the surface of an insect can help lower the insect's body temperature (i.e., sweating).

The insect's heart rate reflects its metabolic rate. A higher metabolism leads to a faster heart rate.

As an insect's ventilation (breathing) rate increases, it increases evaporation of water (i.e., panting).

Figure 3. Possible cooling mechanisms in a grasshopper.

Dr. Prange used specific instruments to record the grasshopper's heart rate, ventilation (breathing) rate, and evaporative water loss. He compared these with the organism's body temperature in the three graphs below (Figure 4). From his findings, the ventilation rate increased drastically around a temperature of 45 °C (left graph). The figures for heart rate and evaporative water loss are also shown below.

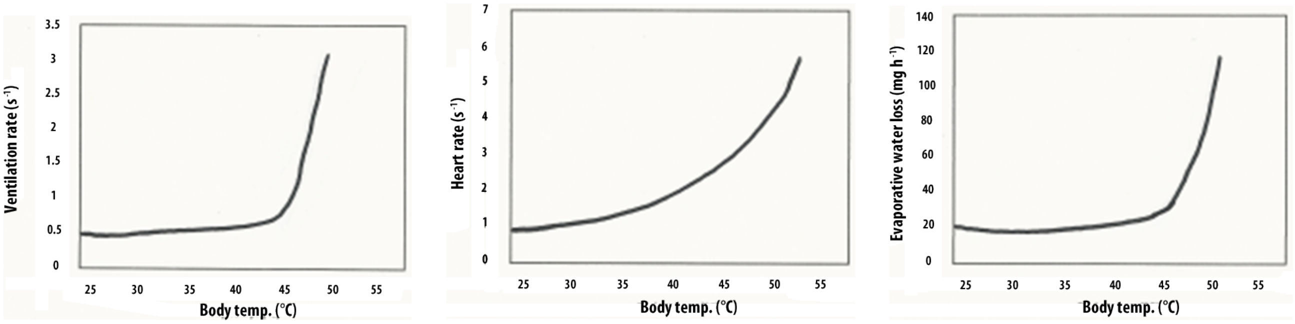


Figure 4. Grasshopper heart rate, ventilation rate, evaporative water loss. Adapted from Prange (1990).

Questions

7. From the graphs in Figure 4, does the increase in ventilation rate appear to be most likely related to an increase in metabolic need (heart rate), or an increase in the amount of water evaporation? Explain your reasoning.

8. Compare the graphs in Figure 4 to the graph in Figure 2. What appears to happen to grasshoppers at a temperature of around 48–50 degrees?

9. From Dr. Prange's study, can it be supported that the grasshoppers were using evaporative cooling? Why or why not?

Bonus

10. Water has an unusually high heat of vaporization (~40kJ/mol), allowing it to be used for evaporative cooling. What do you think would happen if a different compound was used for evaporative cooling—for example, methane (~8kJ/mol)?

References

Asres, A. and N. Amha. 2014. Physiological adaptation of animals to the change of environment: a review. *J. Biology, Agriculture, and Healthcare* 4(25): 146–51.

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