

THERMAL ACCLIMATION

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Abstract:

Temperature affects the rates of most physical, biochemical, and physiological functions. However, the biochemistry and physiology of animals are not necessarily at the mercy of thermal environment and their body temperature because biochemical and physiological rates can be adjusted to compensate for variations in temperature. Such compensation is called acclimatization if it occurs in nature, and acclimation if it is induced in the laboratory. Flatworm's show an acute response in thermal changes and their activity varies in great deals; the linear velocity (LV) changes by 78% less when the temperature drops from $20\text{ }^{\circ}\text{C} \pm 1.5$ to $4^{\circ}\text{C} \pm 1$, and its angular velocity (AV) is reduced by 79%. Nevertheless, when looking that the opposite the scenario inverts; the LV is increased by 52% when the temperature rises from $4^{\circ}\text{C} \pm 1$ to $20\text{ }^{\circ}\text{C} \pm 1.5$, and the AV goes up by 45%. This is a very quickly response taking in account the time between the thermal change and the collection of results which was less than 1 min.

Introduction:

Apparently adaptation is a designed feature of an organism, which has evolved by natural selection over numerous generations to solve the problems of survival and reproduction faced by the organism's ancestors (Pough *et al*, 2002).

Intuitively, adaptations are familiar to us as those striking aspects of the living world that, as Darwin aptly put it, "most justly excite our admiration". Organisms and all their parts have a pervasive air of purpose about them, a highly organized complexity, a precision and efficiency, an ingenious utility (Romer & Parsons, 1986).

A favourite example of Darwin's was the woodpecker's beak and tongue, finely engineered for excavating insects buried in tree barks; and there is the no less impressive engineering of brain and behaviour, ensuring that the hard-won prey is to the woodpecker's taste. There are many other examples, such as the warning calls of vervet monkeys, differentiated according to whether the predator is a python, martial eagle, or leopard – and to which the hearers respond differentially by looking down, looking up, or running to trees; the gentle mottling of a camouflaged insect contrasted with the vibrant warning colours of a closely related species that mimics the livery of a noxious animal; the female sage grouse, which fastidiously rejects suitors that bear

visible parasite scars; the scoops on the penis of a damselfly, which remove rival sperm before the owner deposits his own; the air conditioning of termite mounds, maintaining a constant temperature in spite of the savannah's extremes of climate; and orchids luring pollinators by their likeness to female bees, clamping their pollen on the deceived visitor's back (Pough *et al*, 2002).

However adaptations are not always external and visible to the human eye; some occur at cell and molecular level and are extremely important for the organism to withstand changes in its own environment and in last instance to assure its survival and welfare.

The range of tolerance for a species, or even individuals within a population, is not rigid and unalterable. In fact, animals are generally able to readjust their range of tolerance over a period of time in response to alterations in their environment – acclimatization and acclimation are an example of this but the boundary between these two concepts is quite thin and they often touch each other. Acclimation is the term used to describe this readjustment phenomenon when it is observed in the natural environment. The physiological adaptation of an animal's range of tolerance to an altered environment, when investigated under the controlled conditions of a research laboratory, is called acclimation, rather than acclimatization (Withers, 1992).

Changes in temperature are constant in a dynamic environment and change quite dramatically from a season to the other; under these conditions is imperative for an organism to adapt and tolerate such variations, and in this case an acclimation of some body and metabolic functions must occur. As the metabolic demands of small organisms is sometimes much higher than the bigger ones the changes are more difficult to support. The invertebrates are the most successful and abundant group of organisms on earth and they as well have to cope with the changes in their habitat, which are normally more unstable due to their small size.

Flatworms constitute the phylum Platyhelminthes; tapeworms constitute the class Cestoda, flukes the class Trematoda, and planarians constitute the class Turbellaria (Ruppert & Barnes, 1994).

Flatworm is the common name for soft-bodied, usually parasitic animals, the simplest of animals possessing a "head". They are bilaterally symmetrical and somewhat flattened, and most are elongated. Three main classes are included in the flatworm phylum: tapeworms, which in the adult stage are parasitic in the digestive tracts of animals; flukes, which are parasitic in various parts of different animals; and planarians, which are free-living and non-parasitic. Some authors also include a group of unsegmented marine worms; other authors consider them a separate phylum (Peckenik, 2000).

The ectoderm (outer surface) of the free-living flatworms is usually covered with hair-like cilia; in the parasitic forms the ectoderm usually secretes a hardened material called cuticle. A well-developed musculature, found directly under the epidermis (skin layer), allows the body to expand and contract, thus changing the body shape to a remarkable degree. Vivid pigmentation is sometimes present in the free-living forms, but the parasitic forms are usually unpigmented. Flatworms have no true body cavity; the spaces between the organs are filled with a compact connective tissue called parenchyma. Except in the simplest forms, one end of the body (the head) is more specialized for sensory perception, and locomotion takes place in the direction of specialization. The oral and genital openings are on the ventral (under) side. When present, the digestive tract is either sac-like or branched and has only one

opening. This opening may be equipped with a sucker, as in the flukes, or, as in most planarians, it may have a well-developed pharynx. The nervous system consists of a network with a large ganglion (brain), at the front of the body, and various longitudinal nerve cords forming the principal parts. Sensory cilia and “eye spots” may be present in the free-living forms and in the larvae of the parasitic forms. The flatworm has no blood or vascular system. Specialized cells possessing cilia, called flame cells, lead from the interior to one or more openings in the exterior by means of a network of tubes. Together these structures form the excretory system. The reproductive system is highly complex and occupies a large portion of the interior of the animal. Although flatworms are almost all hermaphroditic (both male and female reproductive organs are present in each individual), the eggs and sperm are formed separately. These germ cells either leave the body by separate openings or enter a common chamber, called the genital atrium. Many flatworms are also able to reproduce asexually both by binary fission – that is, by pinching themselves apart to become two – and by regeneration, producing an entire new worm from a piece that has been cut off. (Peckenik, 2000; Ruppert & Barnes, 1994).

Free-living flatworms are found in almost every kind of environment, on land and in fresh and salt water. They eat a variety of foods, including plankton, carrion, earthworms, snails, insect larvae, and small crustaceans. The parasitic flatworms often display a complicated life cycle, which typically requires development in two or three hosts before completion (Ruppert & Barnes, 1994).

Method:

Two different groups of flatworms were separated and maintained in fresh, aerated water. One group was kept at laboratory temperature ($20\text{ }^{\circ}\text{C} \pm 1.5$), (named “Warm”) and the other at $4^{\circ}\text{C} \pm 1$ (named “Cold”) for three weeks under similar light conditions.

During the experiment a flatworm, maintained at one of the temperatures was placed in a petri dish covered with an acetate sheet. Using a fine marker pen, the movements of the flatworm were traced for a period of 2 minutes, being the procedure repeated 2 times. Then the flatworm was placed in opposite conditions (i.e. flatworm from ambient temperature water in cold water or flatworm from cold water into ambient temperature water) and the procedure of tracing the movement for 2 minutes was done once more.

When working with cold water the petri dish was placed in a dissection tray and ice around it was used to maintain the water temperature.

Using a protactor, ruler and a piece of thread the average speed of the animal was estimated as well as the average of turning (in degrees).

Results:

After following the method the measures were made and the data from the 2 different groups can be seen in tables 1.0 and 1.1; in which AG stands for acclimation group, T for temperature, LV for linear velocity, and AV for angular velocity.

Table 1.0 – Warm group data

AG	T (°C)	LV (mm/sec)	AV (deg/min)
Cold	4	0.27	64
Cold	4	0.44	350
Cold	4	0.7108	470.25
Cold	4	0.196	30
Cold	4	0.958335	454.25
Cold	4	0.7	116.5
Cold	4	0.57	142.75
Cold	20	1	348
Cold	20	1.48	1497.5
Cold	20	1.2165	390.25
Cold	20	0.8475	229.25
Cold	20	0.67915	259.75
Cold	20	1.3	156.5
Cold	20	0.854	87

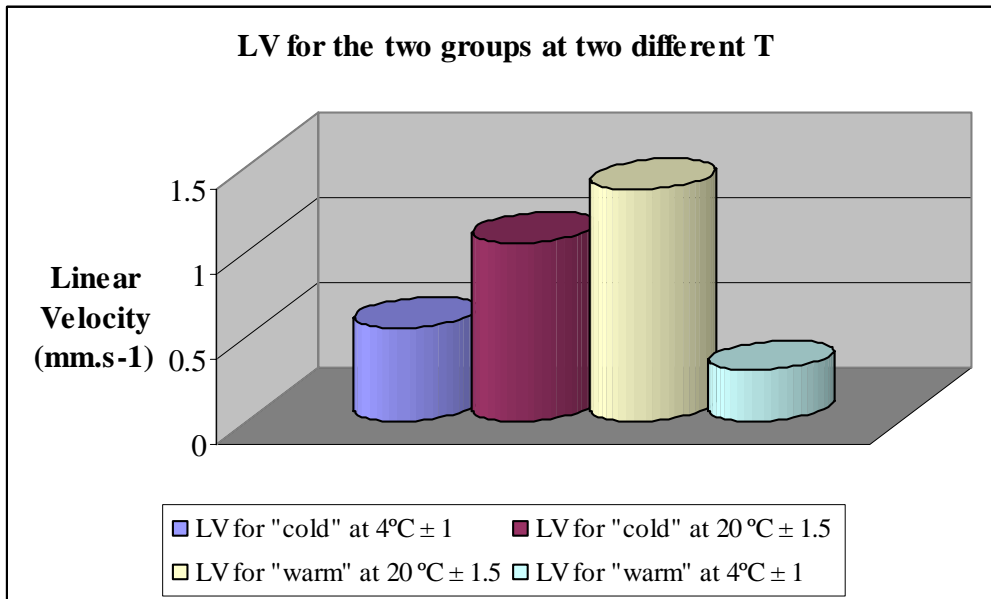
Table 1.1 – Cold group data

AG	T (°C)	LV (mm/s)	AV (deg/min)
Warm	20	1	128.5
Warm	20	1.045	525
Warm	20	1.4775	151.25
Warm	20	1.595	426.75
Warm	20	1.2025	321.5
Warm	20	1.46	404
Warm	20	1.795	207.75
Warm	4	0.6	152.5
Warm	4	0.125	125
Warm	4	0.11665	144
Warm	4	0.122	3.75
Warm	4	0.32085	30.25
Warm	4	0	0
Warm	4	0.795	48.5

The data was analysed based on averages of different variables considered. The temperature of the organism was denominated “initial” and the temperature at which it was posterior exposed of “acclimated”.

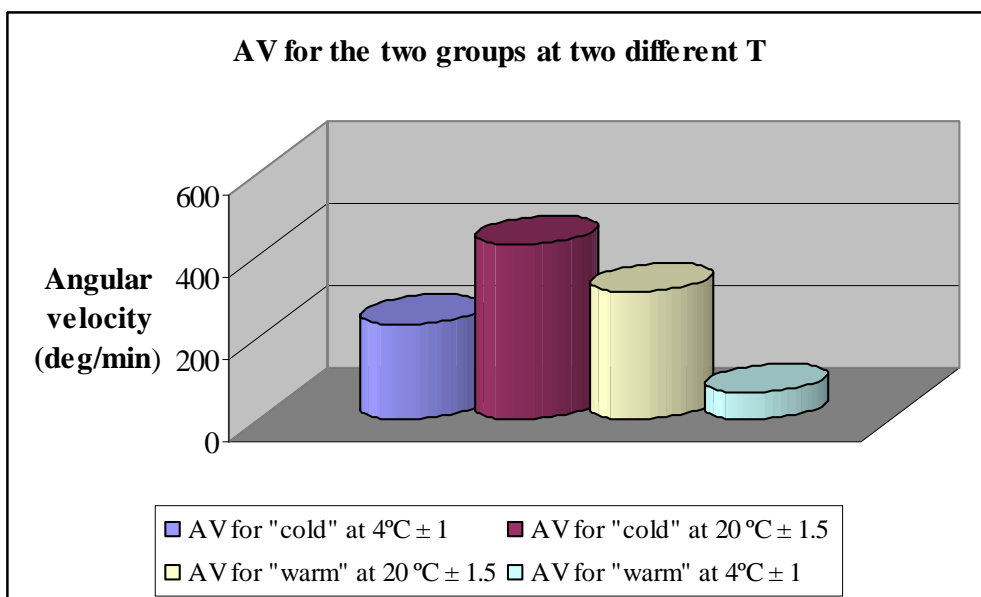
The average of Linear Velocity (LV) for the “cold” in the “initial” condition ($4^{\circ}\text{C} \pm 1$) was of $0.5493\text{mm}\cdot\text{s}^{-1}$, and in the “acclimated” condition ($20^{\circ}\text{C} \pm 1.5$) of $1.053\text{mm}\cdot\text{s}^{-1}$, an increase of 52% in activity compared with the “initial” value. The average for LV of the “warm” group during the “initial” temperature ($20^{\circ}\text{C} \pm 1.5$) was of $1.368\text{mm}\cdot\text{s}^{-1}$, while the LV for the “acclimated” temperature ($4^{\circ}\text{C} \pm 1$) was of $0.2971\text{mm}\cdot\text{s}^{-1}$ – a reduction of 52% in activity. Values for the different groups and temperatures can be seen in figure 1.0.

Figure 1.0 – Linear velocity for “cold” and “warm” groups at the respective temperatures



When looking at the averages for the angular velocity (AV) for the “initial” temperature (4°C ± 1) of the “cold” group was of 232.5deg/min, and when exposed to the “acclimated” temperature (20 °C ± 1.5) it was 424.1deg/min, an increase of 45%. The “warm” group at the “initial” temperature (20 °C ± 1.5) showed an AV of 309.25deg/min while during exposure to the “acclimated” temperature (4°C ± 1) it was of 65.07deg/min – approximately 79% less when compared with the previous value. Values for the different groups and temperatures can be seen in figure 1.1.

Figure 1.1 – Angular velocity for “cold” and “warm” groups at the respective temperatures



Discussion and conclusions:

Temperature is a measure of the average thermal motion of molecules. It dramatically affects reaction rate, as indicated by the activation energy and values of biochemical and physiological rates (Withers, 1992). It is relatively easy to infer this just by looking at the values obtained for the activity of flatworms. When subjected to a temperature of $4^{\circ}\text{C} \pm 1$ the activity was always reduced then when at a higher temperature. Even the flatworms maintained at $4^{\circ}\text{C} \pm 1$ for 3 weeks showed an increase of 52% in their LV and an increase of 45% in their AV. In the other hand flatworms at $20^{\circ}\text{C} \pm 1.5$ showed a decrease in their LV of 78% and a decrease of 79% for their AV. These findings have a reason behind what the human eye can see. Several adjustments and changes at the cellular level occur to make the organism able to tolerate this drastic changes in temperature.

Thermal acclimation is an important physiological phenomenon that allows cold-adapted animals to have “normal” biochemical and physiological rates at low temperature, compared to warm-adapted animals. There are a number of adaptive changes in both enzyme structure and function, and lipid membrane structure and physical properties, which occur during thermal acclimation. Other changes are seen in metabolic functions, cells, and tissues; the transport of ions and metabolites, and the nervous system are also affected following a temperature acclimation period (Withers, 1992; Johnson, 2004).

There are a number of potential strategies to manipulate enzyme catalytic rate and achieve thermal acclimation. These include altering the enzyme concentration, substrate concentration, catalytic efficiency of enzymes, and the intracellular environment, e.g., ionic concentration and pH. Enzyme concentration and catalytic efficiency are generally the more important adjustments during thermal acclimation. However, the general utility of achieving thermal acclimation by adjustments of enzyme concentration is questionable. Synthesizing high concentrations of enzyme to compensate for its thermally induced catalytic inefficiency is not necessarily an optimal solution. For example, glycolytic enzymes may show little, or even inverse, acclimation in concentration. When acclimated at a low temperature there is the adoption of less constrained and rigid tertiary structures to maintain activity, achieved at the expense of thermal stability. The catalytic efficiency of enzymes is generally temperature dependent. However, homologous enzymes can counteract the effect of temperature on catalytic rate by variation in their free energy of activation. Another potential mechanism for compensation of thermal modulation of enzyme catalytic efficiency is modification of the intracellular environment in which the enzymes function. Changes in the microenvironment of enzymes with acclimation include the modification of membrane fluidity (Withers, 1992; Johnson, 2004).

The physical properties of lipids and especially lipids bilayer membranes are markedly influenced by temperature. Biological membranes exist in “semi-crystalline” state that is functionally intermediate between a rigid solid lipid (lipids at low temperature) and a highly fluid lipid state (lipids at high temperature). The maintenance of a normal homeoviscous lipid state in biological membranes is essential to the functioning of the membrane. The membrane lipids from varying ambient temperatures show changes in fatty acid composition that are adaptive for maintenance of the homeoviscous state. The variation in fatty acid composition of membrane lipids is accomplished by regulating the chain length and polar head group composition or degree of saturation and the decrease in membrane fluidity is usually

correlated with an increase the proportion of unsaturated fatty acids. The homeoviscous state of a membrane has great significance to membrane-bound enzyme catalysis. Membrane fluidity would influence the catalytic activity of enzymes that must undergo conformational changes during catalysis, e.g., membrane-bound transport proteins. The fluidity of the lipid bilayer surrounding the enzyme clearly would influence the ability to undergo conformational change. Homeoviscous adaptation may also be important in the movement of electrolytes and non-electrolytes across cell or organelle membranes since the cell and organelle membranes play an important role in permeability changes with the outside of the cell or organelle (Withers, 1992).

Nevertheless these factors already mentioned there are some more variables that contribute for the thermal acclimation phenomenon. Metabolic functions also suffer some modifications such as inverse or paradoxical adaptations – a mechanism to reduce energy expenditure during periods of extreme cold; compensatory adjustments have also been observed at the tissue and cellular level (like oxygen) or organization for maintenance of stability. Mitochondrial oxygen consumption also changes during acclimation and is associated with modifications of aerobic enzyme activity. Some ultrastructural modifications to cell and tissue morphology may occur to compensate for limitations imposed by reduced diffusion at low temperature, thus in cold acclimation the capacity for ATP production increases, particularly in the region of the myofibrils decreasing the diffusion distances for metabolites and ions such as Ca^{2+} and ATP – oxygen however also suffers a decrease in its diffusion rate during acclimation. Absorptive functions can also suffer a partial or complete compensation in response to thermal acclimation. The nervous system is also affected during acclimation and some morphological factors known to be important determinants of conduction velocity such as the sensory cilia (Johnson, 2004).

All the factors mentioned above contribute for a significant change in the locomotory activity of flatworms. There is no optimal acclimation and it locomotory function is clearly reduced when the organism is submitted to a drop in temperature and it increases with it as well. Rates of acclimation also vary, and in flatworms are very fast (a vague term, but it was impossible to determine the speed of acclimation), although the mechanism underlying temperature compensation of the locomotory performance involves the complex changes in nervous system, tissues, cell organization and organelles function.

Document Statistics:

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Images and diagrams:

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