

Biological robustness is a critical and fundamental property of biological systems that characterizes their ability to maintain in the presence of changes and uncertainty [1]. Biological Fragility, on the other hand, refers to the opposite of biological robustness, which describes the susceptibility to dysfunction in the face of perturbations.

Thermoregulatory mechanisms in humans are examples of biological robustness. Maintaining a stable body temperature is essential for humans because it allows for efficient metabolic processes and physiological functions to occur within a narrow range of temperatures. Human regulates their body temperature through various mechanisms such as sweating, panting, shivering, and adjusting their metabolic rate. These processes are controlled by the hypothalamus in the brain, which receives and processes temperature information throughout the body, allowing the human to maintain a stable internal temperature regardless of the external environment [2].

The thermoregulatory mechanisms that enable humans to maintain stable body temperature also pose a trade-off in terms of biological fragility. High temperatures in the environment can lead to heatstroke, a potentially life-threatening condition that results from the failure of the body's thermoregulatory system. The body's thermoregulatory system is maintained by various control feedback loops that can become overwhelmed at high external temperatures, leading to a breakdown in the system [3]. This highlights the delicate balance between the benefits of maintaining a stable body temperature and the risk of biological fragility in extreme environmental conditions [1].

Biological robustness is a fundamental aspect of survival due to its contribution to adaptability and genetic stability. Organisms with robust biological systems can effectively respond to changing environmental conditions, thereby maintaining homeostasis which is critical for survival [1]. For instance, when a plant is exposed to high levels of light, it can adapt by producing additional pigments that protect it from excessive light, such as chlorophyll-binding proteins. Similarly, if a plant is exposed to high temperatures, it can acclimate by producing heat shock proteins that shield its cells from damage. Organisms lacking biological robustness are more vulnerable to environmental variations, limiting their ability to adapt to new challenges, ultimately reducing their survival and fitness.

Moreover, biological robustness plays an essential role in maintaining gene diversity, which contains beneficial traits, thus enabling organisms to survive in new or challenging environments. According to Félix et al., biological robustness is characterized by the absence or low level of variation when faced with a given incoming variation [4]. Beneficial traits increase an organism's chances of survival in a particular environment by enhancing its capacity to acquire resources, resist diseases, or evade predators. For instance, the ability to camouflage can aid an organism in avoiding predators, while a stronger immune system can help it resist diseases. If genes were not stably inheritable, the transfer of beneficial traits across generations would be impeded, reducing a population's ability to adapt to specific environments.

The consequences of biological fragility can be severe and impact an organism's ability to survive and thrive in its environment. As Khammash et al. suggested, the strong dependence of circuits on parameters that are unexpected to change serves as a useful analogy to illustrate biological fragility [5]. When biological systems experience unexpected perturbations, much like a circuit breaking down, they may fail to react appropriately and suffer significant consequences as a result. This can lead to a breakdown in homeostasis and an increased risk of injury, illness, and even death.

Biological fragility is an inevitable consequence of improved robustness, as there is a trade-off between the two [1]. However, there are some ways to mitigate the risk of biological fragility. One approach is to make the biological system less robust, which can reduce the likelihood of unexpected fragility. Another approach is to protect the biological system from vulnerable perturbations, which can prevent biological fragility from occurring.

In conclusion, biological robustness is a critical property of biological systems that enables them to adapt and maintain genetic stability in the face of environmental changes. This robustness is exemplified by thermoregulatory mechanisms in humans, which help maintain a stable body temperature. However, this robustness also poses a risk of biological fragility, which can result in dysfunction and even death in extreme environmental conditions. Biological fragility is characterized by the susceptibility to dysfunction in the face of perturbations, and it is a trade-off for biological robustness. While it is impossible to completely eliminate biological fragility, there are ways to mitigate its risk. One approach is to make the biological system less robust, while another is to protect it from vulnerable perturbations. Ultimately, understanding biological robustness and fragility is critical for the survival and adaptation of organisms in their environment.

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