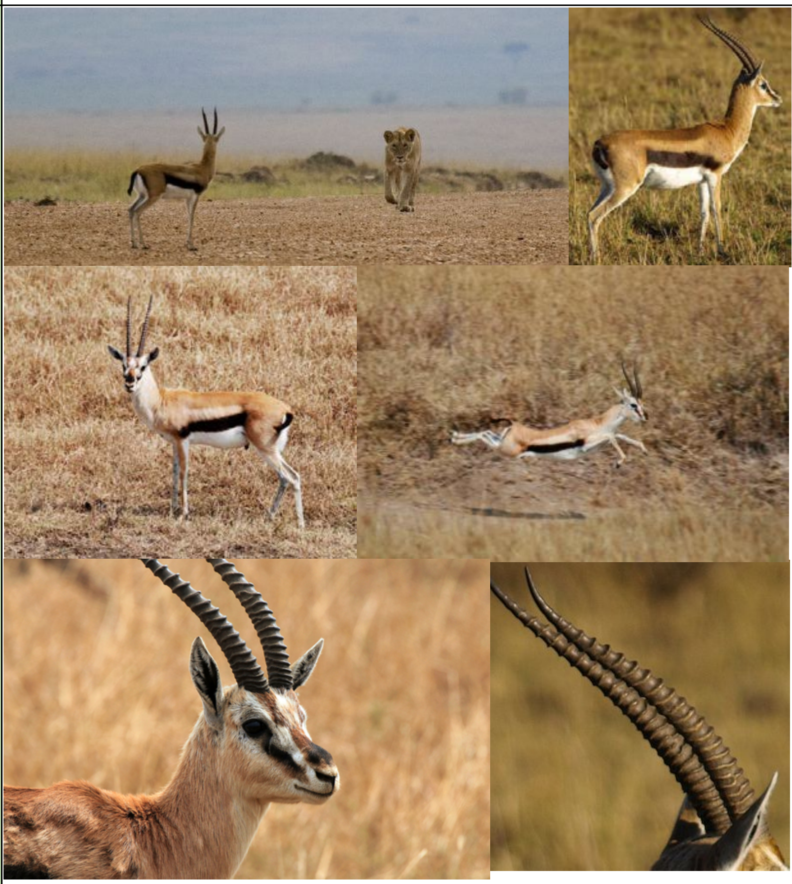
生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	頸動脈網冷卻大腦 (Carotid rete cools brain)
生物系統 LIVING SYSTEM	湯氏瞪羚 *Gazella thomsonii* (Thomson's gazelle)
功能類別 FUNCTIONS	#維持體內平衡 #保護免受溫度危害 #Maintain homeostasis #Protect from temperature
作用機制標題	湯氏瞪羚的頸動脈網藉由對流熱交換冷卻大腦 (The carotid rete of the Thomson's gazelle cools its brain via counter-current heat exchange.)
生物系統/作用機制示意圖	

作用機制摘要說明 (SUMMARY OF FUNCTIONING MECHANISMS)

湯氏瞪羚 (Thomson’s gazelle) 生活在東非的稀樹草原上，除了會曝曬於高溫之下，還得面對大型貓科動物，包括獵豹、獅子、花豹。紀錄中，這些瞪羚的奔跑速率可達每小時 43-50 哩。如此爆炸性的速度可能會增加代謝速率，隨之產生高達四十倍的熱能。要消散這些熱能是很困難的，特別是在水分缺乏的乾旱環境下，且動物也須避免在皮膚蒸發冷卻過程中損失過多的水分。

大腦是對高溫特別敏感的身體部位，因此像是湯氏瞪羚之類的有蹄類，會使用頸動脈

網 (carotid rete) 作為對流熱交換的結構，維持大腦有低於身體的溫度。此種網狀結構由動脈與靜脈構成，位於大腦底部的血竇 (sinus)中。溫暖的血液從頸動脈流進大腦，進入血竇中的小動脈網，由於靜脈血從鼻腔通道返回，其流向相反，因此部分熱能會在這裡轉移至較低溫的靜脈血液中；然後冷卻的動脈血才繼續流至大腦中。

奔跑中的湯氏瞪羚，體溫的上升幅度遠高於大腦溫度，測量兩者的差異可達 2.7℃。如獵豹等的捕食者，當身體和大腦的溫度達到 40.5℃時必須停止奔跑；而瞪羚在體溫超過 43℃、但大腦溫度低於 40.5℃時，仍可持續奔跑。保持低溫大腦的能力，使得瞪羚面對捕食者的追擊，仍可擁有一線生機，因其耐力超越獵豹，因後者無法維持較低溫的大腦。

對流熱交換結構，在許多生物的構造中都可發現到。雖然工程師對這些機制也相當瞭解，若仔細研究此類大自然的設計，對於設計人們住居的熱能控制系統可能會有幫助。

The Thomson’s gazelle lives in the East African savannah where is it exposed to high temperatures and predation by big cats, like the cheetah, lion, or leopard. These gazelles have been recorded to run at up to 43-50 miles per hour. Such a burst of speed may raise the metabolic rate, and thus heat production, by as much as 40 fold. Dissipating such heat loads is difficult, especially in arid environments where water is scarce and an animal needs to avoid losing too much through evaporative cooling.

The brain is a part of the body that is particularly sensitive to high temperature. Hence some ungulates, like the Thomson’s gazelle, use a counter-current heat exchanging structure known as the carotid rete to keep the brain cooler than the body. The rete is a configuration of arteries and veins in a sinus at the base of the brain. Warm blood flowing to the brain travels from the carotid artery into a network of small arteries within the sinus, where it transfers some of its heat to cooler venous blood flowing the opposite direction as it returns from the nasal passages. The cooled arterial blood then continues toward the brain.

In the running Thomson’s gazelle, body temperature rises more than brain temperature such that a difference between brain and body temperature has been measured at 2.7℃. A predator like the cheetah must stop running when its body and brain temperature reaches 40.5℃, but the gazelle can keep running as its body temperature rises above 43℃ without its brain temperature exceeding 40.5℃. The ability to keep a cool head can thus give the gazelle a survival edge in these predatory pursuits as he can outlast the cheetah who cannot maintain a cooler brain.

Counter-current heat exchangers can be found in many organisms in many configurations. While such mechanisms are well known to engineers, a close look at the design of those used by nature may be useful in designing thermal control systems of human habitations.

文獻引用 (REFERENCES)
「在偶蹄動物 (artiodactyls) 中，要進入大腦的動脈血會流經大腦底部的頸動脈網...它由數百條小動脈組成，由頸動脈分支出去，經過 10-15 毫米後再次聚合，並進入大腦動脈環 (circle of Willis)。此血管網會嵌入海綿竇 (cavernous sinus) 中，此系統通過眼角靜脈 (angularis oculi vein)，從上呼吸道的蒸發表面帶回較低溫的血流。這是一種相當大容量的熱能交換器：在湯氏瞪羚這種羚羊中，可觀察到大腦溫度和軀幹溫度之間有 2.7℃的梯度差異。」(Jessen 1998: 281) “In artiodactyls, the arterial blood destined for the brain passes through the carotid rete at the base of the brain...It consists of hundreds of small arteries, arising from branches of the carotids and after 10-15 mm joining again to enter the circle of Willis. The rete is embedded in the cavernous sinus, which carries cool blood returning via the angularis oculi vein from the evaporating surfaces of the upper respiratory tract. This is a heat exchanger of considerable capacity: in one species of antelope, Thomson’s gazelle, a 2.7℃ gradient between Tbrain and Ttrunk was observed.” (Jessen 1998: 281)
參考文獻清單與連結 (REFERENCE LIST)
Taylor, C.R., V. Roundtree. (1973). Temperature regulation and heat balance in running cheetahs: a strategy for sprinters? *American Journal of Physiology* 224: 848-851. (https://doi.org/10.1152/ajplegacy.1973.224.4.848) Baker, M. A. and J. N. Hayward. (1968). The influence of the nasal mucosa and the carotid rete upon hypothalamic temperature in sheep. *The Journal of Physiology* 198: 561-579. (https://doi.org/10.1113/jphysiol.1968.sp008626)
延伸閱讀
生物系統延伸資訊連結 (LEARN MORE ABOUT THE LIVING SYSTEM/S)
https://en.wikipedia.org/wiki/Gazella_thomsonii
撰寫/翻譯/編修者與日期
高阡珈翻譯 (2019/04/26)；譚國鋈編修 (2020/04/15)；施習德編修 (2020/12/15)
AskNature 原文連結
https://asknature.org/strategy/carotid-rete-cools-brain/