生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	變色龍發射「彈道」舌頭 (Chameleons Launch “Ballistic” Tongues)
生物系統 LIVING SYSTEM	變色龍 (Chameleons)
功能類別 FUNCTIONS	#轉換機械能量 #捕捉、吸收或過濾生物 #Transform mechanical energy #Capture, absorb, or filter organisms
作用機制標題	為了遠距離捕捉獵物，變色龍擁有一套協調的身體部位系統，能夠以高速和強大的力量發射它們的舌頭。 (To catch prey from a distance, chameleons have a coordinated system of body parts that shoots out their tongues with high speed and power.)
生物系統/作用機制示意圖 (確認版權、註明出處；畫質)	

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

變色龍擁有令人驚嘆的彈道舌頭，這使它們成為捕捉獵物的高效利器。這種非凡的生物機制涉及到多個身體部位的協調運作，其中包括一根被彈性組織和肌肉所包裹的細長管狀骨骼。

當變色龍發現獵物時，它們迅速收縮舌肌，將能量蓄積到彈性組織內的膠原纖維中。當舌頭發射時，這些蓄能的膠原纖維迅速釋放出動能，驅動舌頭以驚人的速度伸出，迅速捕捉獵物。(Jurrian et al., 2004)

這種自然機制不僅使變色龍能夠迅速捕食，還為科學家提供了靈感，進一步研究如何開發更高效的彈道運動系統和材料。這些研究成果將有望應用於彈道學、機器人技術、以及假肢等領域，為人類帶來更多的科技進步和應用價值。

Chameleons possess incredible ballistic tongues, making them efficient hunters. This extraordinary biological mechanism involves the coordinated operation of multiple body parts, including a slender tubular bone encased in elastic tissue and muscle.
When chameleons spot prey, they rapidly contract their tongue muscles, storing energy in the collagen fibers within the elastic tissue. Upon tongue projection, these energy-stored collagen fibers rapidly release kinetic energy, propelling the tongue at astonishing speed to swiftly capture prey.
This natural mechanism not only enables chameleons to efficiently capture prey but also inspires scientists to further explore the development of more efficient ballistic motion systems and materials. These research outcomes hold promise for applications in fields such as ballistics, robotics, prosthetics, and beyond, contributing to technological advancements and practical innovations for humankind.

文獻引用 (REFERENCES)

變色龍舌頭的彈道投射是動物王國中快速能量釋放的極端範例。它依賴著複雜的生理結構，以及組織彈性、膠原纖維各向異性、主動肌肉收縮、應力釋放和幾何形狀之間的精心平衡。提出了一個基於大變形彈性的變色龍舌頭動力學的一般生物物理模型。該模型涉及三個獨立耦合的子系統：舌內鞘的能量學、激活加速肌肉的力學和舌頭延伸的動力學。這三個系統共同闡明了變色龍科獵食中的關鍵物理原則。(Moulton et al., 2016)

為了捕捉獵物，變色龍會以彈道方式將它們的舌頭彈射出去，距離可達到身體長度的 1.5 倍，加速度可高達 500 m/s^2。在變色龍舌頭的核心部分是由加速肌包圍的圓柱形舌骨架。投射機制中的關鍵結構可能是一層圓柱形的結締組織層，包圍著舌骨架。…這層組織層至少包含 10 個包覆舌骨架的鞘。外部部分與加速肌前部相連，內部部分與收縮結構相連。鞘中含有膠原纖維的螺旋陣列。在投射之前，鞘通過加速肌的結合半徑收縮和靜水伸長，估計 *C. melleri* 的平均功率為 144 W kg–1。當加速肌和鞘的加載部分 (the loaded propotion) 開始滑過舌骨架的尖端時，舌頭投射被觸發。彈簧在推動舌骨架的圓頂時向外部放鬆，使儲存在螺旋纖維中的彈性能量可同時推動舌蓋、加速肌和收縮結構向前加速。隨著多層彈簧滑過光滑且潤滑的舌骨架尖端，能量釋放持續進行…因此，我們確定了一種與標準工程設計非常不同的獨特的彈射機制。(de Groot et al., 2004)

小型變色龍能夠將它們的舌頭投射到比例上更遠的距離，投射距離可達到身體長度的 2.5 倍。此外，研究表明，小型變色龍物種在舌頭投射期間能夠產生高達 2,590 m/s^2（或 264 g）的峰值加速度，以及在舌頭投射期間的每公斤體重功率輸出值可達到 14,040 W/kg，這些數值在爬行動物中是最高的。這些比例關係不僅突顯了這個家族先前被低估的性能能力，還表明在測試具有隱藏的動力放大機制的運動時，考慮體型尺寸的潛在效用，以及不同的代謝需求可能如何促進形態演化。(Chirstopher V. et al., 2016)

環境溫度通過對肌肉收縮生理學的影響影響爬行動物的身體活動和生態。爬行動物在溫度下降 10°C 時，衝刺、游泳和跳躍的表現至少下降 33%，伴隨著肌肉功率的類似下降。我們提出由彈性組織反彈提供動力的彈道運動比依賴直接肌肉力量的運動更不依賴溫度。我們發現，變色龍中彈性驅動的彈道舌頭投射在 20°C 的溫度範圍內保持高性能。與非彈性、肌肉驅動的舌頭收縮相比，峰值速度和功率在溫度下降 10°C 時只下降了 10

%–19%，而後者下降超過 42%。這些結果顯示彈性回彈機制迴避了低溫對肌肉速率性能的限制，從而減少了舌頭投射的溫度依賴性。(Anderson et al., 2010)

The ballistic projection of the chameleon tongue is an extreme example of quick energy release in the animal kingdom. It relies on a complicated physiological structure and an elaborate balance between tissue elasticity, collagen fibre anisotropy, active muscular contraction, stress release and geometry. A general biophysical model for the dynamics of the chameleon tongue based on large deformation elasticity is proposed. The model involves three distinct coupled subsystems: the energetics of the intralingual sheaths, the mechanics of the activating accelerator muscle and the dynamics of tongue extension. Together, these three systems elucidate the key physical principles of prey-catching among chameleonides. (Moulton et al., 2016)

To capture prey, chameleons ballistically project their tongues as far as 1.5 body lengths with accelerations of up to 500 m s–2. At the core of a chameleon's tongue is a cylindrical tongue skeleton surrounded by the accelerator muscle. The key structure in the projection mechanism is probably a cylindrical connective–tissue layer, which surrounds the entoglossal process. … This tissue layer comprises at least 10 sheaths that envelop the entoglossal process. The outer portion connects anteriorly to the accelerator muscle and the inner portion to the retractor structures. The sheaths contain helical arrays of collagen fibres. Prior to projection, the sheaths are longitudinally loaded by the combined radial contraction and hydrostatic lengthening of the accelerator muscle, at an estimated mean power of 144 W kg–1 in *C. melleri*. Tongue projection is triggered as the accelerator muscle and the loaded portions of the sheaths start to slide over the tip of the entoglossal process. The springs relax radially while pushing off the rounded tip of the entoglossal process, making the elastic energy stored in the helical fibres available for a simultaneous forward acceleration of the tongue pad, accelerator muscle and retractor structures. The energy release continues as the multilayered spring slides over the tip of the smooth and lubricated entoglossal process… Thus, we have identified a unique catapult mechanism that is very different from standard engineering designs. (de Groot et al., 2004)

Small chameleons are able to project their tongues proportionately longer distances, with projection lengths reaching 2.5 body lengths. Additionally, small chameleon species are shown to be capable of producing peak accelerations during tongue projection of up to 2,590 m s−2, or 264 g and mass-specific power output values during tongue projection of up to 14,040 W kg−1, values that are the highest reported among amniotes. These scaling relationships not only highlight the previously underestimated performance capability of the family, but also the potential utility of taking body size into account when testing for movements harbouring cryptic power amplification mechanisms and how varying metabolic demands may help drive morphological evolution. (Chirstopher V. et al., 2016)

Environmental temperature impacts the physical activity and ecology of ectothermic animals through its effects on muscle contractile physiology. Sprinting, swimming, and jumping performance of ectotherms decreases by at least 33% over a 10 °C drop, accompanied by a similar decline in muscle power. We propose that ballistic movements that are powered by recoil of elastic tissues are less thermally dependent than movements that rely on direct muscular power. We found that an elastically powered movement, ballistic tongue projection in chameleons, maintains high performance over a 20 °C range. Peak velocity and power decline by only 10%–19% with a 10 °C drop, compared to >42% for nonelastic, muscle-powered

tongue retraction. These results indicate that the elastic recoil mechanism circumvents the constraints that low temperature imposes on muscle rate properties and thereby reduces the thermal dependence of tongue projection. (Anderson et al., 2010)
參考文獻清單與連結 (REFERENCE LIST) **Harvard 或 APA 格式**
Moulton, D. E., Lessinnes, T., O'Keeffe, S., Dorfmann, L., & Goriely, A. (2016). The elastic secrets of the chameleon tongue. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 472(2188), 20160030. de Groot, J. H., & van Leeuwen, J. L. (2004). Evidence for an elastic projection mechanism in the chameleon tongue. Proceedings of the Royal Society of London. Series B: Biological Sciences, 271(1540), 761-770. Anderson, C. V. (2016). Off like a shot: scaling of ballistic tongue projection reveals extremely high performance in small chameleons. Scientific reports, 6(1), 18625. Anderson, C. V., & Deban, S. M. (2010). Ballistic tongue projection in chameleons maintains high performance at low temperature. Proceedings of the National Academy of Sciences, 107(12), 5495-5499.
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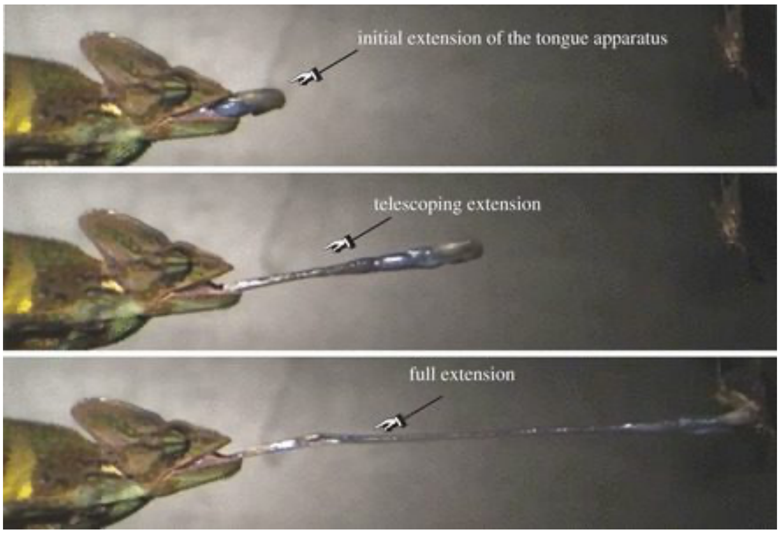
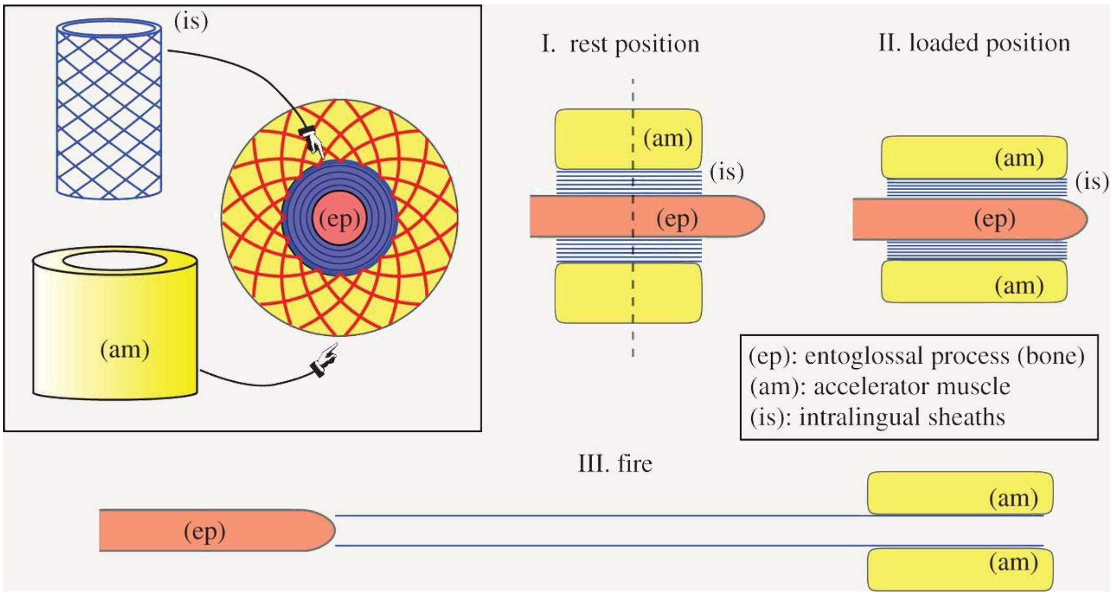


To catch prey, chameleons have a highly coordinated system of bone, muscle, and connective tissue that shoots long distances out their tongues at high speed and power.



Chameleons' ballistic tongues are the result of a coordinated system of body parts: bone (entoglossal process = ep), collagen fibers (intralingual sheaths = is), and accelerator muscle (am).