生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	附肢以加快的速度打擊 (Appendage Strikes With Amplified Speed)
生物系統 LIVING SYSTEM	螳螂蝦 Stomatopoda (Mantis shrimp)
功能類別 FUNCTIONS	#獲取、吸收、或過濾生物體 #儲存能量 #保護免受動物危害 #機械能轉型 # Capture, Absorb, or Filter Organisms # Store Energy # Protect From Animals # Transform Mechanical Energy
作用機制標題	螳螂蝦的捕獵附肢透過功率放大，以驚人的速度和力量打擊獵物 (The raptorial appendage of the mantis shrimp strikes with tremendous speed and force through power amplification.)
生物系統/作用機制 示意圖	

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

螳螂蝦 (mantis shrimp) 是一種兇猛的海洋甲殼類 (marine crustacean)，牠使用特化 (specialized) 的前肢 (forelimb)（稱為捕獵附肢 raptorial appendage）來捕捉獵物。作為「擊碎者 (smasher)」的螳螂蝦會用錘子般的物體敲擊破壞螺類 (snail) 和其他軟體動物 (mollusk) 的外殼，使牠們柔軟的身體暴露在外以便食用。螳螂蝦的打擊甚至可以擊破水族箱玻璃。牠能做到這些事是依靠捕獵附肢上堅硬的圓鼓踵狀物 (bulbous heel)，這在覓食和保護上能起作用。像大多數螳螂蝦的身體一樣，捕獵附肢由堅硬的外骨骼 (exoskeleton) 材料組成。它分為四個部分：長節 (merus)（離身體最近）容納主要的肌肉群。接下來是腕節 (carpus)、掌節 (propodus)、然後是指節 (dactyl)，這些部位根據螳螂蝦的種類而形狀有所不同。「擊碎者」在它們的指節上有堅硬的踵狀物。雖然螳螂蝦有許多不同的種類，但捕獵附肢都使用相同的原理來產生快速而強力的運動。此原理稱為功率放大 (power amplification)。

功率放大系統透過將肌肉的收縮和運動分為兩個連續的步驟：負載階段 (load phase)和釋放階段 (release phase)，來放大由相對較慢的肌肉收縮產生的動力。

在螳螂蝦鉗子的負載階段，長節的屈肌 (flexor) 收縮，使長節硬化的一小部分接合 (engage) 外骨骼的其它部分，其作用類似於閂鎖 (latch)，將整個附肢固定在適當位置並防止運動。同時，長節的伸肌 (extensor) 收縮並彎曲長肢的其他外骨骼部分（鞍狀和腹面閂 saddle and ventral bar），它們像壓縮的彈簧一樣儲存能量。這些屈肌和伸肌是拮抗性 (antagonistic) 的，這意味著如果它們單獨收縮就能產生相反的運動（使你的手臂彎曲的二

頭肌 biceps 和使手臂伸展的三頭肌 triceps 是一對拮抗性肌肉）；但是，同時收縮可以使大型伸肌緩慢地收縮，而附肢會屈曲並「閂上」。伸肌的緩慢收縮不會移動附肢，而是將能量儲存為彈性勢能，本質上是在準備打擊獵物時加載彈簧。

當螳螂蝦準備打擊獵物時，釋放階段始於屈肌放鬆以釋放閂鎖。附肢的鞍形閂和腹面閂會彈回其原始形狀，釋放其儲存的彈性能，並導致指節以高達45英里/小時的速度向前旋轉！由於釋放階段的附肢運動僅持續數毫秒 (millisecond)，因此大大增強了螳螂蝦的攻擊力。

The mantis shrimp is an aggressive marine crustacean that uses specialized forelimbs (called raptorial appendages) to capture its prey. Mantis shrimp that are “smashers” use a hammer-like strike to destroy the shells of snails and other mollusks, exposing the soft body of the animal so that it can be eaten. The mantis shrimp’s strike can even smash aquarium glass. It does this with a tough bulbous heel on the raptorial appendages, which function in both feeding and protection. The raptorial appendage, like most of the mantis shrimp’s body, is composed of tough exoskeletal material. It is divided into four segments: the merus (closest to the body) houses the major muscle groups. Next is the carpus, propodus, and then the dactyl, which differs in shape depending on the species of mantis shrimp. “Smashers” bear the hard heel on their dactyls. While there are many different species of mantis shrimp, the raptorial appendages use the same principle to generate rapid and forceful movement. This principle is called power amplification.

Power amplification systems amplify the mechanical power generated by relatively slow muscle contractions by separating muscle contraction and movement into two sequential steps: the load phase and the release phase.

In the load phase for the mantis shrimp raptorial appendage, flexor muscles in the merus contract to engage small hardened parts of the merus against other parts of the exoskeleton, which function like a latch to keep the whole appendage in place and prevent movement. At the same time, extensor muscles in the merus contract and bend other exoskeletal parts of the merus (the saddle and ventral bars), which store energy like a compressed spring. These flexor and extensor muscles are antagonistic, meaning that they produce opposite movements if they contract individually (your biceps, which flexes the arm, and triceps, which extends the arm, are a pair of antagonistic muscles); however, contracting at the same time enables the large extensor muscle to contract slowly while the appendage is flexed and “latched.” Instead of moving the appendage, the extensor muscle’s slow contraction stores energy as elastic potential energy, essentially loading a spring while it prepares to strike.

When the mantis shrimp is ready to strike, the release phase begins as the flexor muscles relax to release the latch. The appendage’s saddle and ventral bars spring back to their original shape, releasing their stored elastic energy and causing the dactyl segment to rotate forward at speeds up to 45 miles/hour! Because the appendage motion in the release phase takes place over only milliseconds, the mantis shrimp greatly increases the power of its strike.

文獻引用 (REFERENCES)

「一個假性 (hypothesized) 的彈性儲存結構，鞍狀閂，只貢獻了總測量力的大約11%，因此推斷儲存彈性能量的主要位置是在捕獵附肢長節中的礦化腹面閂中。」(Zack et al. 2009: 4002）

「骨骼結構可以將功 (work) 引導到彈性材料中；當這些結構放鬆到靜止狀態時，能量釋放的時間比基本的肌肉收縮要短得多，從而達到功率放大。使用彈性結構來放大骨骼肌 (skeletal muscle) 的功率輸出，對於動物迅速地加速 (acceleration) 至關重要。」(Zack et al. 2009: 4002)

「兩個關鍵結構已被確認為能量儲存結構—長節V型和鞍形閂。蟬形齒指蝦蛄 (peacock mantis shrimp) 外骨骼的一個「腹面閂」，從長節V型閂延伸到腹面閂...成為四連桿系統 (four-bar linkage system) 的一部分，用來耦合 (couple)儲存彈性能，達到腕節的快速旋轉。」(Zack et al. 2009: 4003)

「所有動物產生快速運動的能力都會面臨一些限制—肌肉緩慢地短距離收縮。動物通過使用功率放大機制而克服了這限制，這在演化史 (evolutionary history) 上反覆出現。這些機制減少了運動的持續時間，從而增加了速度和加速度 (Alexander, 1983; Alexander and Bennet-Clark, 1977; Gronenberg, 1996a)。」(Patek et al. 2007: 3677)

「螳螂蝦與所有甲殼類一樣，透過一對拮抗的肌肉來控制運動，這些肌肉交替地使附肢外展 (abduct) 和內收 (adduct)。但是，在功率放大打擊獵物時的負載階段，螳螂蝦同時地使用捕獵附肢中腕節和長節部分的拮抗性肌肉，因為要準備進行高功率打擊 (Fig. 1)。具體地說，牠們在長節中收縮大型、緩慢的伸肌，而在長節中收縮的屈肌固定了一對骨片 (sclerites) 以防止運動 (Burrows, 1969; Burrows and Hoyle, 1972; McNeill et al., 1972)。當伸肌完全收縮而且螳螂蝦準備好打擊時，屈肌會停止固定，放開骨片，然後附肢迅速朝著其目標向外旋轉 (Burrows, 1969; Burrows and Hoyle, 1972; McNeill et al., 1972)。」(Patek et al. 2007: 3678)

"One hypothesized elastic storage structure, the saddle, only contributed approximately 11% of the total measured force, thus suggesting that primary site of elastic energy storage is in the mineralized ventral bars found in the merus segment of the raptorial appendages." (Zack et al. 2009: 4002)

"Skeletal structures can channel work into elastic materials; when these structures are allowed to relax to their resting state, energy is released over a much shorter time scale than the underlying muscle contraction, thereby resulting in power amplification…The use of elastic structures to amplify the power output of skeletal muscle is fundamental to rapid accelerations in animals." (Zack et al. 2009: 4002)

"Two key structures have been identified as probable energy storage structures – the meral-V and saddle…A "ventral bar" of exoskeleton that extended from the meral-V to the ventral surface of the merus in the peacock mantis shrimp…and acts as part of a four-bar linkage system to couple stored elastic energy to the rapid rotation of the carpus." (Zack et al. 2009: 4003)

"All animals face an overriding constraint on their ability to produce fast movements – muscles contract slowly and over small distances. Repeatedly over evolutionary history, animals have overcome this limitation through the use of power amplification mechanisms. These mechanisms decrease the duration of movement and thereby increase speed and acceleration (Alexander, 1983; Alexander and Bennet-Clark, 1977; Gronenberg, 1996a)." (Patek et al. 2007: 3677)

“Mantis shrimp, like all crustaceans, control movement with antagonistic pairs of muscles that alternately abduct and adduct their appendages. However, in the load phase of a power-amplified strike, mantis shrimp simultaneously activate the antagonistic muscles connecting the carpus and merus segments in the raptorial appendage as they prepare for a high-powered strike (Fig. 1). Specifically, they contract large, slow extensor muscles in the merus while contracted flexor muscles in the merus brace a pair of sclerites to prevent movement (Burrows, 1969; Burrows and Hoyle, 1972; McNeill et al., 1972). When the extensor muscles have fully contracted and the animal is ready to strike, the flexor muscles turn off, releasing the sclerites, and the appendage rapidly rotates outward toward its target (Burrows, 1969; Burrows and Hoyle, 1972; McNeill et al., 1972).” (Patek et al. 2007: 3678)

參考文獻清單與連結 (REFERENCE LIST)

Zack, T. I., T. Claverie, and S. N. Patek. (2009). Elastic energy storage in the mantis shrimp's fast predatory strike. *J. Exp. Biol.* 212: 4002-4009. (https://doi.org/10.1242/jeb.034801)

Knight, K. (2009). Elastic energy powers mantis shrimp punch. *J. Exp. Biol.* 212: iii. (https://doi.org/10.1242/jeb.040691)

Patek, S. N., M. V. Rosario, and J. R. A. Taylor. (2013). Comparative spring mechanics in mantis shrimp. *J. Exp. Biol.* 216: 1317-1329. (http://dx.doi.org/10.1242/jeb.078998)

延伸閱讀:

生物系統延伸資訊連結 (LEARN MORE ABOUT THE LIVING SYSTEM/S)

撰寫/翻譯/編修者與日期

許群讓翻譯 (2021/04/05);譚國鋈編修 (2021/07/06);林有駿編修 (2021/10/20);陳柏宇編修 (2021/10/28)

AskNature原文連結

https://asknature.org/strategy/appendage-strikes-with-amplified-speed/