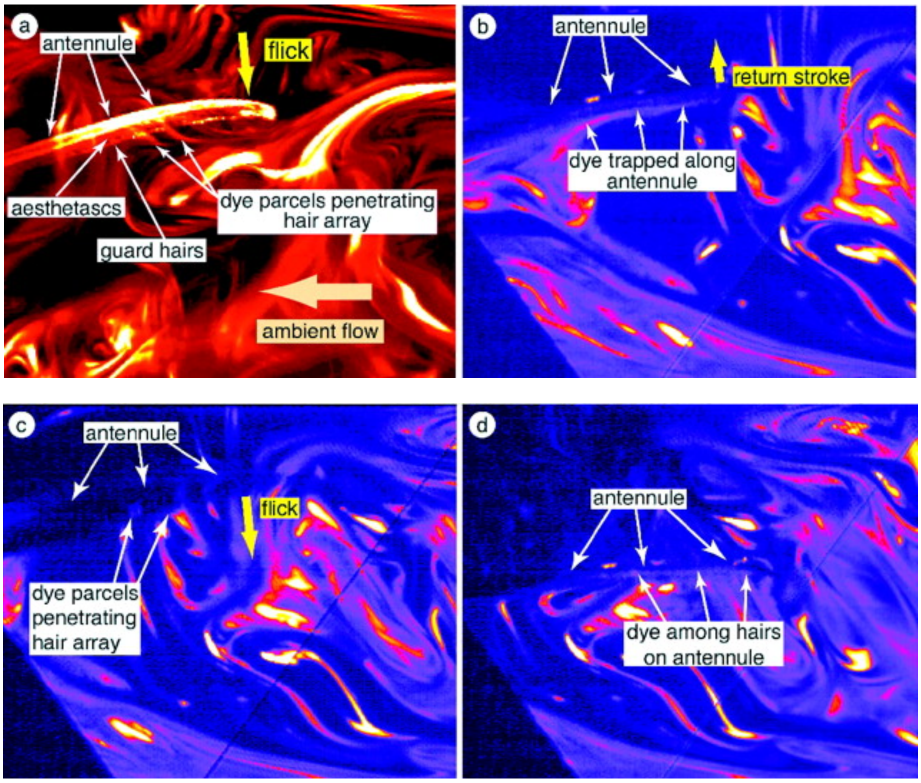
生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	生物傳感器捕獲水下氣味 (Sensors Trap Underwater Odors)
生物系統 LIVING SYSTEM	眼斑龍蝦 (*Panulirus argus*)
功能類別 FUNCTIONS	#捕獲、吸收或過濾化學實體 #感知環境中的化學物質（氣味、味道等） #Capture, Absorb, or Filter Chemical Entities #Sense Chemicals (Odor, Taste, etc.) From the Environment
作用機制標題	眼斑龍蝦的觸角可以捕獲水，利用毛髮狀的化學感測受器來辨識氣味 (Antennules of the spiny lobster trap water to identify odors using chemosensory hairs.)
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)

眼斑龍蝦有兩個用於防禦的長觸角。它透過隱藏在水下洞穴和縫隙中來躲避白天的掠食者，當夜晚見不到太陽時就會出來覓食，如蝸牛、螃蟹和腐爛的物質。它使用一對較小的觸角（antennules）來嗅出並捕捉獵物。

觸角上覆蓋著成排列的毛髮狀受體，稱為美學感受器(aesthetascs)，使龍蝦能夠檢測氣味等化學訊號。受體排列成鋸齒形，此設計可將氣味分子捕獲在受體附近。龍蝦透過上下擺動觸角來感知環境。

透過研究眼斑龍蝦的觸角在染色水槽中彈動的動力學模式，科學家觀察到彈動運動如何影響水流。根據觸角在水中移動的速度，毛髮狀受體的排列方式會有所不同。

當快速向下穿過漂浮的水下氣味軌跡時，毛髮陣列就像篩子一樣，讓水沿著觸角通過受體，從亂流中捕獲氣味分子。在較慢的向上輕彈過程中，觸角在返回起始位置時就像一

個實心槳，在向下俯衝的過程中保持收集相同的樣本。這種物理交互作用使受體有機會讀取這個時間和空間下，捕獲到的水中氣味濃度之特定模式。
儘管尚不清楚龍蝦如何定位氣味來源的細節，但它會收集有關氣味模式的資訊。每一次輕彈都會給它一個單獨且獨特的樣本——周圍環境的氣味快照。隨著觸角每次彈動，氣味圖像也會發生變化，龍蝦可以更了解氣味來源。

潛力
因為其擁有的精細控制能力，生物醫學科學家已經提出使用類似觸角的刷子來捕獲和處理諸如單細胞之類的微觀物體。
以更長遠的發展而言，透過讀取物理模式進行檢測的水下感測器可以應用於無人機，以搜尋化學物質、污染物或武器。能夠顯示微小震動的感測器甚至可以幫助預測地震等事件。
「……龍蝦嗅覺觸角透過流體動力學改變湍流氣味羽流濃度的時空模式。當觸角輕彈時，水在快速向下衝程期間會滲透到它們的化學感應毛髮陣列中，將精細的濃度模式帶入受體區域。這種空間模式在下劃過程中因沿著觸角的流動而變得模糊，但在較慢的返回過程中保留下來，直到下一次輕彈時才會消失。」(Koehl et al. 2001:1948)
「這種龍蝦毛髮般捕獲裝置的工程實現，透過靜電力驅動…透過擾動流體力場並操縱周圍流體的雷諾數來驅動生物物體，從而實現微觀物體操縱的功能。 …這些仿生靜電雙壓電晶片執行器可以避免傳統工具的一些缺點，並且是非接觸式和非侵入性操縱微/奈米生物物體的潛在工具。」

The Caribbean spiny lobster (Panulirus argus) has two long antennae used for defense. It avoids daytime predators by hiding in underwater caves and crevices, coming out as the sun goes down to search for food such as snails, crabs, and decaying matter. It uses a pair of smaller antennae called antennules to sniff out and track down snacks.
The antennules are covered in rows of hair-like receptors called aesthetascs that allow the lobster to detect chemical signals such as odors. The aesthetasc hairs are arranged in a zig-zag pattern. The antennule design works to trap odor molecules near the receptors. The lobster senses the environment by flicking its antennule down and up.
By studying a mechanical lobster programmed to flick real *P. argusa* antennules in an underwater dye flume, scientists observed how the flicking motion affected water flow. The aesthetasc hair arrangement works differently depending on how quickly the antennule moves through the water.
When flicked quickly downward through a drifting underwater scent trail, the hair array acts like a sieve, allowing water to pass through the sense receptors all along the antennule, grabbing odor molecules from the turbulent water currents. On the slower upward flick, the antennule acts like a solid paddle as it returns to its starting position, holding on to the same sample it collected on the downstroke. This physical interaction gives the receptors the chance to read the specific patterns of odor concentration in the water captured at that moment in time and space.
Though it’s unknown exactly which details the lobster uses to locate the odor source, it gathers information about the pattern in the wisps of odor. Each flick gives it a separate and distinct sample – a scent snapshot of its surroundings. As the scent picture changes with each new antennule flick, the lobster can learn more about the odor source.
Because of its delicate control abilities, biomedical scientists have already proposed using an antennule-like brush to capture and work with microscopic objects such as single cells.

On a larger scale, underwater sensors that detect by reading physical patterns could have applications in drones that search out chemicals, pollution, or weapons. Sensors that can interpret small disturbances might even help predict events such as earthquakes.
文獻引用 (REFERENCES)
"…lobster olfactory antennules hydrodynamically alter the spatiotemporal patterns of concentration in turbulent odor plumes. As antennules flick, water penetrates their chemosensory hair array during the fast downstroke, carrying fine-scale patterns of concentration into the receptor area. This spatial pattern, blurred by flow along the antennule during the downstroke, is retained during the slower return stroke and is not shed until the next flick." (Koehl et al. 2001:1948) "The engineering implementation of this lobster-hair-like capturing device, which is actuated by the electrostatic force… drives the biological objects via disturbing the fluid field and manipulating the Reynolds number of the surrounding fluid to achieve the function of micro-object manipulation.…These biomimetic electrostatic bimorph actuators could avoid some of the drawbacks of conventional tools and are potential tools for the non-contact and non-invasive manipulation of micro/nano bio-objects." (Chang, et al. 2005:812)
參考文獻清單與連結 (REFERENCE LIST) **Harvard 或 APA 格式**
Lobster Sniffing: Antennule Design and Hydrodynamic Filtering of Information in an Odor Plume *Science* | 27/07/2002 | M. A. R. Koehl **A lobster-sniffing-inspired method for micro-objects manipulation using electrostatic micro-actuators** *J. Micromech. Microeng.* | 26/02/2005 | Chieh Chang, Chia-Fang Chiang, Cheng-Hsiang Liu, Cheng-Hsien Liu
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撰寫/翻譯/編修者與日期
陳采竺翻譯 (2024/03/21)；陳柏宇編修 (2024/11/30)
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