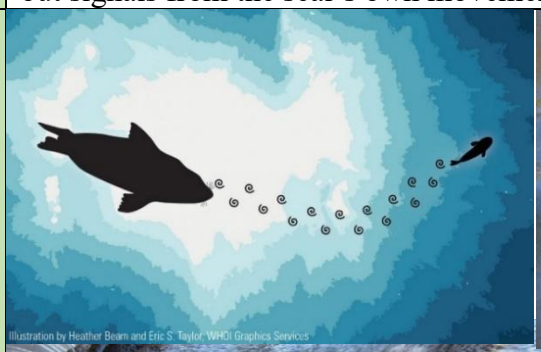
生物策略表

類別	生物策略 (Strategy)
生物策略 Strategy	海豹鬍鬚如何在水下追蹤獵物 (How Seal Whiskers Track Prey Underwater)
生物系統 Living system	港灣海豹 *Phoca vitulina* (Harbor seal)
功能類別 FUNCTIONS	#獲取、吸收、或過濾生物 #感應動作 #液體中導航 #從噪音中區分訊號 #Capture, absorb, or filter organisms #Sense motion #Navigate through liquid #Differentiate signal from noise
作用機制標題	港灣海豹的鬍鬚透過抵銷自身運動造成的訊號，感應獵物游泳留下的尾波 (Harbor seal whiskers sense the wake left by swimming prey by cancelling out signals from the seal's own movement.)
生物系統/作用機制示意圖	  

作用機制摘要說明 (Summary of functioning mechanisms)

介紹

在陰暗的深海裡，敏銳的視力對捕獵而言並不是那麼實用。海豚跟鯨魚的捕獵依靠聽覺大於視覺。鯊魚則是名符其實地透過牠們有名的嗅覺搜尋海水中的血腥味，還可以偵測生物發出的微弱電波訊號。

港灣海豹 (harbor seal)（如同其他海豹跟海獅）增強了另一種感官 (sense) 來獲取食物。牠們能在水中感覺到非常細微 (ever-so-slight) 的動作，並跟隨魚類游動的尾波 (wake)。他們自動導引的裝置是鬍鬚 (whisker)，這種古怪的構造也是牠們理想地適合在水中活動的原因。

策略

鬍鬚自動物體表突出來感應周遭環境。訊號被傳送到鬍鬚基部，這是一個由大量神經細胞 (nerve cell) 構成的網絡，使其敏感得就像指尖一樣。貓的鬍鬚有大約 200 個神經末梢

(nerve ending)，但港灣海豹的鬍鬚有高達 1500 個神經末梢，而且更為精密調整 (finely tuned)。但牠們成功的真正秘密在於鬍鬚的構造。

如果你曾看過車子的舊式天線 (old-fashioned antenna) 或自行車上的旗子，你會注意到當車子移動時，它們會如何搖動或飄揚。氣流 (air current) 會在它們周圍盤旋，造成它們振動。（鬍鬚的科學名稱是鬚髯 vibrissae，出自「振動」的拉丁文。）

你可能會預期當海豹游泳時鬍鬚會有如上述類似的表現。但取而代之的是，一些驚人的事發生了：鬍鬚如熱刀切開奶油般切開了水，而且在波浪裡幾乎沒有擺動 (wiggling)。

關鍵在於它的外形。海豹的鬍鬚在剖面圖來看並不是圓形，而是橢圓形。而且他們的前緣 (leading edge) 並不是直線形，而是像波浪般進進出出的樣式 (in-and-out pattern)。這種構造的設計可以抵銷水在鬍鬚周圍的旋轉運動，所以當海豹移動時鬍鬚並不會振動。

取而代之的是，它們保持靜止且準備好去感應其他游泳生物產生的擾動。鬍鬚在迎面而來的漩渦 (swirl) 裡上下振動，就像滑雪者在有障礙物的坡道上來回地迴旋 (slalom) 一樣。

較大的魚產生較大的漩渦，而越快的魚會在尾波中留下更多漩渦。透過以鬍鬚感應這些漩渦，海豹可以在目標經過三十秒後的一次感應內，精準地辨識潛在目標的大小、速度和方向，並追蹤牠的下游蹤跡 (downstream trail)。

潛力

工程師正在複製海豹鬍鬚的設計來發展水下感測器 (underwater sensor)。這些感測器可以用於監測魚類及海洋哺乳類；追蹤漏油事件的油污流動；找出從海底溫泉 (seafloor hot spring) 中飄傳來的溫水漣漪；對威脅水下建築物的渦流 (turbulent current) 提供警告；以及為水下機器運載工具 (robotic vehicle) 提供更好的導航方式。它們還可能為海軍 (navy) 提供另一種偵測船隻和潛水艇的方法—這些船隻變得越來越安靜來躲避傳統的聲納偵測法 (sonar detection)。

Introduction

In the dim depths of the ocean, sharp eyesight isn't so useful for hunting. Dolphins and whales listen rather than look. Sharks famously and literally smell blood in the water and can also detect weak electrical signals that living things give off.

Harbor seals (and likely other seals and sea lions) have heightened yet another sense to secure meals. They can feel ever-so-slight movements in the water and follow a trail left behind in the wake of swimming fish. Their homing device is their whiskers, whose quirky structure makes them ideally suited to work in water.

The Strategy

But whiskers stick out of animals to sense their surrounding environment. They transmit signals to a rich network of nerve cells at the whiskers' base that make them as sensitive as fingertips. Cat whiskers have some 200 nerve endings. Harbor seal whiskers, with up to 1,500, are even more finely tuned. But the real secret to their success is their structure.

If you've ever seen old-fashioned antennas on cars or flags on bicycles, you'll notice how they sway and flutter when the vehicles move. Air currents swirl around them, causing them to vibrate. (The scientific name of whiskers is "vibrissae," which comes from the Latin word for "vibrate.")

You'd expect seal whiskers to behave similarly when seals swim through water. But instead, something remarkable happens: The whiskers cut through water like a hot knife through butter, barely wiggling in the waves.

The key is their shape. Seal whiskers aren't circular in cross-section, but oval-shaped. And their leading edges aren't straight, but have a wavy, in-and-out pattern. This structural design neutralizes the swirling action of water around the whiskers, so that the whiskers don't vibrate when the seals move.

Instead, they remain still and ready to respond to disturbances generated by other swimmers. The whiskers vibrate up and down, over and under oncoming swirls the way a skier slaloms back and forth down a slope of oncoming obstacles.

Bigger fish produce larger swirls, and faster fish leave more of them in their wakes. By feeling these swirls with their whiskers, seals can precisely identify the size, speed, and direction of potential targets and follow their downstream trail, in one test 30 seconds after a target had passed by.

The Potential

Engineers are already copying the design of seal whiskers in an effort to develop underwater sensors. They could be used to monitor fish and marine mammals; track flowing oil spill plumes; discover ripples of warm water wafting from seafloor hot springs; provide warning of turbulent currents that threaten underwater structures; and give underwater robotic vehicles a better way to navigate. They may also give navies another way to detect ships and submarines—which have become more and more quiet to elude traditional methods of sonar detection.

文獻引用 (REFERENCES)

「被蒙住眼睛的 (blindfolded) 的海豹能夠透過牠們形狀特殊的鬍鬚來追蹤移動中動物留下的漩渦尾波，並識別三十秒前通過的物體，這是一項令人印象深刻的壯舉，因為流動特徵的速率(velocities)低至 1mm/s。海豹在游泳時感應，因此牠們的鬍鬚足夠敏感到能偵測小規模的流量變化，同時還能抵銷自身所產生的流動雜訊。…我們於此定義並說明一種新穎的流動機制，透過造成大幅度的鬍鬚「迴旋」反應，使人造鬍鬚具有跟海豹一樣獨特的波動幾何形狀，當置於尾流中能偵測微小流量波動的特徵。」

「近期研究顯示，港灣海豹 (*Phoca vitulina*) 僅靠鬍鬚就能追蹤水下的尾波蹤跡。鬍鬚特殊的幾何形狀被認為有抑制震動引起的漩渦之作用。在這樣的幫助下，我們開發了壓電 MEMS 流量感測器 (piezoelectric MEMS flow sensor)，這利用高長寬比 (aspect ratio) 的微小鬍鬚以高敏感度來感測水下的流動。」

"Blindfolded harbour seals are able to use their uniquely shaped whiskers to track vortex wakes left by moving animals and identify objects that passed by 30 s earlier, an impressive feat, as the flow features have velocities as low as 1 mm s^{-1}. The seals sense while swimming, hence their whiskers are sensitive enough to detect small-scale changes in the flow, while rejecting self-generated flow noise. … Here we identify and illustrate a novel flow mechanism, causing a large-amplitude 'slaloming' whisker response, which allows artificial whiskers with the identical unique undulatory geometry as those of the harbour seal to detect the features of minute flow fluctuations when placed within wakes."

"Recent studies reveal that Harbor seals (*Phoca vitulina*) are capable of performing underwater wake tracking using their vibrissae alone. It is believed that the unique geometry of the whiskers may play a role in suppressing vortex-induced vibrations. In this work, we developed piezoelectric MEMS

flow sensors that utilize high aspect ratio micro-whiskers to sense flows underwater with high sensitivity."

參考文獻清單與連結（REFERENCE LIST）

Beem, H. R. and M. S. Triantafyllou. (2015). Wake-induced 'slaloming'response explains exquisite sensitivity of seal whisker-like sensors. *J. Fluid Mech.* 783: 306-322. (http://dx.doi.org/10.1017/jfm.2015.513)

Kottapalli, A. G. P., M. Asadnia, J. M. Miao, and M. S. Triantafyllou. (2015). Harbor seal whisker inspired flow sensors to reduce vortex induced vibrations. *28th IEEE International Conference on Micro Electro Mechanical Systems (MEMS)* 889-892. (https://researchers.mq.edu.au/en/publications/harbor-seal-whisker-inspired-flow-sensors-to-reduce-vortex-induce)

Beem, H. (27 January, 2016). Seal Whiskers Inspire Marine Technology. *Oceanus Magazine* 51: 82-85. Retrieved from: https://www.whoi.edu/oceanus/feature/seal-whiskers-inspire-marine-technology/

Dehnhardt, G., B. Mauck, and H. Bleckmann. (1998). Seal whiskers detect water movements. *Nature* 394: 235-236. (https://www.nature.com/articles/28303)

Dehnhardt, G., B. Mauck, W. Hanke, and H. Bleckmann. (2001). Hydrodynamic trail-following in harbor seals (*Phoca vitulina*). *Science* 293: 102-104. (https://doi.org/10.1126/science.1060514)

延伸閱讀:

Lim, J. (28 June, 2017). Modified whiskers handle food. *AskNature*. Retrieved from: https://asknature.org/strategy/modified-whiskers-handle-food/

Ask Nature Team. (18 August, 2016). Whiskers detect details. *AskNature*. Retrieved from: https://asknature.org/strategy/whiskers-detect-details/

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