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A tendon-inspired adjustable-stiffness joint improves swimming speed and efficiency QIANG ZHONG, JIANZHONG ZHU, HILARY BART-SMITH, DANIEL QUINN, University of Virginia — Fish dynamically control muscle stiffness to improve their swimming performance. The advantages of adjustable stiffness are only partially understood, because experiments on robotic tail fins have been limited to 3 Hz or less, whereas fish and fish-inspired robots can flap their tail fins at 10-15 Hz. We present here an actuator that flaps tail fins up to 7 Hz and uses a tunable spring to precisely control the stiffness of the peduncle (tail fin joint) in realtime. Our results show that dynamic stiffness control allows tuna-like fish to maintain high efficiency over a wide range of speeds (0 – 2.5BL/s). We tested this result on a multi-speed long-distance mission (500 m) and found that controlling stiffness while swimming can reduce energy consumption. Three-dimensional Particle Image Velocimetry illustrates what wake structures are responsible for improving efficiency, particularly when peduncle stiffness is optimized at high speeds. Understanding the flow physics governing adjustable tail stiffness at high swimming speeds could guide biological hypotheses about muscle control in fish and offer design ideas for fish-inspired underwater vehicles.

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