Introduction to sonic mechanisms in fish

Xavier Raick[1]

[1] Laboratory of Functional and Evolutionary Morphology, FOCUS, University of Liège, Liège, Belgium

xavier.raick@uliege.be

Compared to other vertebrate taxa, fish have the widest range of sound production mechanisms [1]. In addition, categorizing sonic mechanisms in fish is complicated because one species can use different mechanisms [1]. The two major mechanisms are sonic muscles and stridulation [2]. **Sonic muscles** are muscles that excite the swim bladder and can be either extrinsic or intrinsic. Extrinsic muscles insert on the swim bladder (or on a bone or tendon connected to the swim bladder) and to a bone (e.g., the skull, a rib, a vertebra, or the pectoral girdle) [1,2] while intrinsic muscles attach exclusively to the swim bladder [3] (Fig. 1).

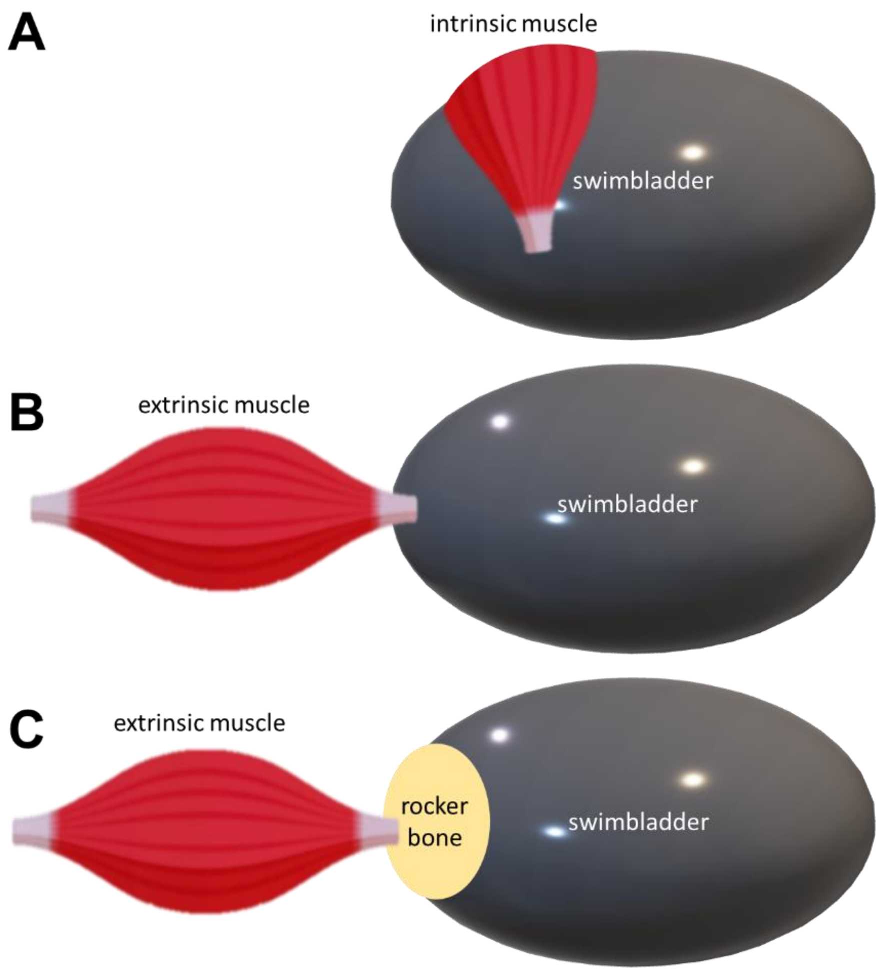

Fig. 1 Schematization of the insertion of sonic muscles on the swim bladder in different teleost taxa. (A) *Lactoria cornuta*, (B) *Synodontis* sp., and (C) *Ophidion rochei* [1,4,5].

Intrinsic muscles are superfast muscles [6–8]. These muscles can produce short-duration pulse-type sounds and long-duration tonal sounds. The fundamental frequency may not change with fish size because the fundamental frequency is determined by the muscle contraction rate [6,9]. These sounds can have a slight frequency modulation caused by a decrease in the sonic muscle contraction rate [2] or have a higher fundamental frequency because two intrinsic muscles contract alternately [8]. Most **extrinsic muscles** are also fast muscles. These muscles are found in many families (e.g., Holocentridae [10], Pimelodidae [11], Sciaenidae [12], and Serrasalmidae [13]) with a wide range of insertions. However, some species use slow muscles [14] associated with a backward movement of the rocker-bone (modification of the first neural arch)[15,16] and the rebound of the swim bladder [16]. Finally, a third condition exists with a fast muscle that primarily operates by rebounding a stretched swim bladder and tendons [2,17]. Many other mechanisms with structures not directly attached to the swim bladder exist in different taxa. These can be tendons (e.g., in Pomacentridae [18]) or muscles (e.g., in Cichlidae [19] and Chaetodontidae [20]) that vibrate or excite the swim bladder. In some taxa, muscles do not show an association with the swim bladder[1] (e.g., Cottidae [21], Gobiidae [22,23], and Scorpaenidae [24]).

The second major category is called **stridulation**, which refers to the friction between skeletal elements such as buccal teeth, pharyngeal teeth, dorsal spines, pectoral spines, fin rays, or vertebrae [1,25–28]. This mechanism is found in numerous taxa (e.g., Balistidae [29], Haemulidae [30], Ictaluridae [31], Mochokidae [32], Loricariidae [32], Osphronemidae [33], Pomacentridae [18], and Sisoridae [34]). The sounds produced through this mechanism generally have a wider frequency bandwidth [35] and contain higher frequencies [36].

In addition to these two main categories, some authors consider a third category of fish sounds known as "**hydrodynamic sounds**", which are produced during fish movements, such as sudden changes in direction or speed [27]. There are also other minor mechanisms, such as in Balistidae, where the sweeping movements of the pectoral fins alternately push a system of three scutes against the swim bladder wall [37,38].

[1] In some taxa, the swim bladder is absent.

REFERENCES

1. Ladich, F.; Fine, M.L. Sound-generating mechanisms in fishes: a unique diversity in vertebrates. In *Communication in Fishes*; Collin, S., Moller, P., Kappor, B., Eds.; Science Publishers: Enfield, 2006; pp. 3–34.

2. Fine, M.L.; Parmentier, E. Mechanisms of Fish Sound Production. In *Sound Communication in Fishes*; Ladich, F., Ed.; Animal Signals and Communication; Springer Vienna: Vienna, 2015; Vol. 4, pp. 77–126 ISBN 978-3-7091-1845-0.

3. Parmentier, E.; Diogo, R. Evolutionary trends of swimbladder sound mechanisms in some teleost fishes. In *Communication in fishes, vol 1*; Ladich, F., Collin, S.P., Moller, P., Kapoor, B.G., Eds.; Science Publisher Inc: Enfield, 2006; pp. 45–70.

4. Parmentier, E.; Marucco Fuentes, E.; Millot, M.; Raick, X.; Thiry, M. Sound production, hearing sensitivity, and in-depth study of the sound-producing muscles in the cowfish (*Lactoria cornuta*). *J. Anat.* **2021**, *238*, 956–969, doi:10.1111/joa.13353.

5. Parmentier, E.; Fine, M.L. Fish Sound Production: Insights. In *Vertebrate Sound Production and Acoustic Communication*; Eds, Suthers, R., Tecumseh, F., Popper, A.N., Fay, R.R., Eds.; Springer, 2016; pp. 19–49 ISBN 978-3-319-27719-6.

6. Skoglund, C.R. Functional analysis of swim-bladder muscles engaged in sound production of the toadfish. *J. Biophys. Biochem. Cytol.* **1961**, *10*, 187–200, doi:10.1083/jcb.10.4.187.

7. Tower, R.W. The production of sound in the drumfishes, the sea-robin and the toadfish. *Ann. N. Y. Acad. Sci.* **1908**, *18*, 149–180, doi:10.1111/j.1749-6632.1908.tb55101.x.

8. Connaughton, M.A. Sound generation in the searobin (*Prionotus carolinus*), a fish with alternate sonic muscle contraction. *J. Exp. Biol.* **2004**, *207*, 1643–1654.

9. Fine, M.; Malloy, K.; King, C.; Mitchell, S.; Cameron, T. Movement and sound generation by the toadfish swimbladder. *J. Comp. Physiol. A Sensory, Neural, Behav. Physiol.* **2001**, *187*, 371–379, doi:10.1007/s003590100209.

10. Winn, H.E.; Marshall, J.A. Sound-Producing Organ of the Squirrelfish, *Holocentrus rufus*. *Physiol. Zool.* **1963**, *36*, 34–44.

11. Sörensen, W. Are the Extrinsic Muscles of the Air-bladder in some Siluroidae and the “Elastic Spring” Apparatus of others Subordinate to the Voluntary Production of

Sounds? What is, according to our Present Knowledge, the Function of the Weberian Ossicles?: A Contribu. *J. Anat. Physiol.* **1895**, 205–229.

12. Ono, R.D.; Poss, S.G. Structure and innervation of the swim bladder musculature in the weakfish, *Cynoscion regalis* (Teleostei: Sciaenidae). *Can. J. Zool.* **1982**, *60*, 1955–1967, doi:10.1139/z82-253.

13. Markl, H. Schallerzeugung bei Piranhas (Serrasalminae, Characidae). *Z. Vgl. Physiol.* **1971**, *74*, 39–56, doi:10.1007/BF00297789.

14. Parmentier, E.; Fontenelle, N.; Fine, M.L.; Vandewalle, P.; Henrist, C. Functional morphology of the sonic apparatus in *Ophidion barbatum* (Teleostei, Ophidiidae). *J. Morphol.* **2006**, *267*, 1461–1468.

15. Fine, M.L.; Lin, H.; Nguyen, B.B.; Rountree, R.A.; Cameron, T.M.; Parmentier, E. Functional morphology of the sonic apparatus in the fawn cusk-eel *Lepophidium profundorum* (Gill, 1863). *J. Morphol.* **2007**, *268*, 953–966, doi:10.1002/jmor.10551.

16. Parmentier, E.; Bouillac, G.; Dragičević, B.; Dulčič, J.; Fine, M.; Dragicevic, B.; Dulcic, J.; Fine, M. Call properties and morphology of the sound-producing organ in Ophidion rochei (Ophidiidae). *J. Exp. Biol.* **2010**, *213*, 3230–3236, doi:10.1242/jeb.044701.

17. Mok, H.-K.; Parmentier, E.; Chiu, K.-H.; Tsai, K.-E.; Chiu, P.-H.; Fine, M.L. An Intermediate in the evolution of superfast sonic muscles. *Front. Zool.* **2011**, *8*, 31, doi:10.1186/1742-9994-8-31.

18. Parmentier, E.; Colleye, O.; Fine, M.L.; Frédérich, B.; Vandewalle, P.; Herrel, A. Sound Production in the Clownfish *Amphiprion clarkii*. *Science (80-.).* **2007**, *316*, 1006–1006, doi:10.1126/science.1139753.

19. Longrie, N.; Van Wassenbergh, S.; Vandewalle, P.; Mauguit, Q.; Parmentier, E. Potential mechanism of sound production in *Oreochromis niloticus* (Cichlidae). *J. Exp. Biol.* **2009**, *212*, 3395–3402, doi:10.1242/jeb.032946.

20. Parmentier, E.; Boyle, K.S.; Berten, L.; Brié, C.; Lecchini, D. Sound production and mechanism in *Heniochus chrysostomus* (Chaetodontidae). *J. Exp. Biol.* **2011**, *214*, 2702–2708.

21. Barber, S.B.; Mowbray, W.H. Mechanism of Sound Production in the Sculpin. *Science*

(80-.). **1956**, *124*, 219–220, doi:10.1126/science.124.3214.219.

22. Lugli, M.; Pavan, G.; Torricelli, P.; Bobbio, L. Spawning vocalizations in male freshwater gobiids (Pisces, Gobiidae). *Environ. Biol. Fishes* **1995**, *43*, 219–231, doi:10.1007/BF00005853.
23. Malavasi, S.; Collatuzzo, S.; Torricelli, P. Interspecific variation of acoustic signals in Mediterranean gobies (Perciformes, Gobiidae): comparative analysis and evolutionary outlook. *Biol. J. Linn. Soc.* **2008**, *93*, 763–778.
24. Bolgan, M.; Soulard, J.; Di Iorio, L.; Gervaise, C.; Lejeune, P.; Gobert, S.; Parmentier, E. Sea chordophones make the mysterious /Kwa/ sound: identification of the emitter of the dominant fish sound in Mediterranean seagrass meadows. *J. Exp. Biol.* **2019**, *222*.
25. Mobius, K.A. *Balistes aculeatus*, ein trommelnder Fisch. *Sitzungsberichte Der Königlich Preuss. Akad. Der Wissenschaften Zu Berlin* **1889**, *14*, 999–1007.
26. Burkenroad, martin D. Notes on the sound-producing marine fishes of Louisiana. *Copeia* **1931**, *1*, 20–28.
27. Tavolga, W.N. *Review of marine bio-acoustics, state of the art : 1964 (technical report)*; Pergamon Press: New-York, 1965;
28. Tavolga, W.N. Sound Production and Detection. In *Fish Physiology*; Hoar, W., Randall, D., Eds.; New York, 1971; pp. 135–205.
29. Moseley, H.N. *Notes by a naturalist on the "Challenger" being an account of various observations made during the voyage of H.M.S "Challenger" round the world, in the years 1872-1876.*; London, 1879;
30. Bertucci, F.; Ruppe, L.; Van Wassenbergh, S.; Compere, P.; Parmentier, E. New insights into the role of the pharyngeal jaw apparatus in the sound-producing mechanism of *Haemulon flavolineatum* (Haemulidae). *J. Exp. Biol.* **2014**, *217*, 3862–3869, doi:10.1242/jeb.109025.
31. Fine, M.L.; McElroy, D.; Rafi, J.; King, C.B.; Loesser, K.E.; Newton, S. Lateralization of pectoral stridulation sound production in the channel catfish. *Physiol. Behav.* **1996**, *60*, 753–757, doi:10.1016/0031-9384(96)00092-3.
32. Kaatz, I.M. The behavioral and morphological diversity of acoustic communication in

a clade of tropical catfishes (Superfamily Ariodei), College of Environmental Science and Forestry - SUNY, Syracuse, NY, 1999.

33. Kratochvil, H. Der Bau des Lautapparates vom Knurrenden Gurami (*Trichopsis vittatus* Cuvier & Valenciennes) (Anabantidae, Belontiidae). *Zoomorphologie* **1978**, *91*, 91–99, doi:10.1007/BF00994156.

34. Mahajan, C.L. SOUND PRODUCING APPARATUS IN AN INDIAN CATFISH SISOR RHABDOPHORUS HAMILTON. *J. Linn. Soc. London, Zool.* **1963**, *44*, 721–724, doi:10.1111/j.1096-3642.1963.tb01638.x.

35. Hawkins, A.D. Underwater Sound and Fish Behaviour. In *The Behaviour of Teleost Fishes*; Springer US: Boston, MA, 1986; pp. 114–151.

36. Ladich, F. Comparative analysis of swimbladder (drumming) and pectoral (stridulation) sounds in three families of catfishes. *Bioacoustics* **1997**, *8*, 185–208, doi:10.1080/09524622.1997.9753362.

37. Raick, X.; Lecchini, D.; Kéver, L.; Colleye, O.; Bertucci, F.; Parmentier, É. Sound production mechanism in triggerfish (Balistidae): a synapomorphy. *J. Exp. Biol.* **2018**, *221*, jeb168948, doi:10.1242/jeb.168948.

38. Parmentier, E.; Raick, X.; Lecchini, D.; Boyle, K.; Vanwassenbergh, S.; Bertucci, F.; Kéver, L. Unusual sound production mechanism in the triggerfish *Rhinecanthus aculeatus* (Balistidae). *J. Exp. Biol.* **2017**, *220*, 186–193, doi:10.1242/jeb.146514.