Fishes in space

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2009

Odd behaviour of fishes in space

As far as I know, the first time fish behaviour was observed in the zero-gravity environment of outer space was in 1973, when a couple of mummichogs, *Fundulus heteroclitus*, were flown in a plastic bag aquarium aboard Skylab. The crew regularly checked how their charges were doing, and they actually filmed the fish's behaviour on day 3 and day 22 of the mission. On day 3, both fish incessantly "dove" – pitched downward – and thus swam in tight circles, as if stuck to the hands of a clock, a behaviour for which the name "looping" was coined. The frequency of looping decreased steadily on subsequent days, until it eventually disappeared. When the fish were filmed again on day 22, they both swam normally with their backs turned towards the cabin's light source (this is a behaviour known as the "dorsal light response" – more on that later). However, episodes of looping could still be triggered by gently shaking the bag aquarium. Fifty eggs at an advanced stage of development had also been taken on board, and 48 of them hatched during the flight. The hatchlings swam normally.[1]

In a follow-up study, 21-day-old mummichogs were flown on Skylab again, and this time astronauts (on day 9) reported a lack of dorsal light response.[2] Other work with carp flown on the space shuttle Endeavour in September 1992 showed a disruption of the dorsal light response for the first 3 days but a gradual recovery thereafter.[3]

The dorsal light response was already well known from earthbound observations. Two mechanisms allow a fish to figure out which way is down (or up) on earth. In the first one, minuscule corpuscles in the inner ear are pulled down by gravity until they set off sensory cells. Depending on the direction of gravity, different cells are stimulated, enabling the fish to know which way is down. This is called the "vestibular righting response", and fishes share this mechanism with land vertebrates, including humans. The second mechanism is simple: the direction where light comes from is interpreted as "up". This is reflected by the tendency of fish to turn their backs towards a light (hence the moniker "dorsal light response"). For fish, light is a good directional cue because in an aquatic environment light usually comes from above and only from above. In terrestrial habitats the ground can reflect light back up, but in any moderately deep body of water no light ever comes from below.

One can demonstrate the dorsal light response by placing a fish in a vertical tube so narrow that the fish has no choice but to take a head-down posture. Then a single light is turned on, on the lefthand side for example. If the dorsal light response is well established in that species and in that individual (the phenomenon, though widespread, is not universal), the fish will swivel inside the tube until its back is turned to the light.

Another way to demonstrate the dorsal light response is to look head on at a fish in an ordinary aquarium, again with the only light coming horizontally from the side. Rather than staying perfectly vertical, the fish will slant its back slightly towards the light. The degree of slant can be taken as a measure of the relative importance of light versus gravity as a cue for the fish to determine which way is up. The more slant there is, the more important light is relative to gravity. If gravity is paramount, the body will remain perfectly vertical. If light is paramount, the fish will swim "on its side", with its back exactly towards the light. In that respect, it is worth noting that in Skylab, where there was no gravity, all fish turned their back completely to the light (except, in some cases, during the first few days of the mission). Light was the only cue they had to figure out which way was "up".

Looping behaviour was also known before 1975, though not really because of earthbound observations. Instead, it had been witnessed in goldfish taken for a ride on parabolic flights in 1969 and 1972. A parabolic flight is achieved when a plane climbs at a relatively steep angle to a high altitude and then briefly levels off before diving down. The manoeuvre (which, if it could be seen from the side, would describe the general shape of a parabola) creates an upward centrifugal force that completely counteracts gravity (the counteracting is made easy by the fact that gravity at high altitude is weaker). The zero-gravity phase lasts for less than a minute. All goldfish taken on such flights had looped without fail during the zero-gravity phase. Some fish had also performed spinning movements, like corkscrews.

In the same way that a transfer from normal gravity to zero gravity induces looping, raising a fish in conditions of higher than normal gravity (this is done by putting an aquarium in a huge centrifuge and letting it turn for weeks on end) induces looping once the fish is brought back to normal conditions.[4]

There is no convincing explanation for why fishes loop or spin.

Motion sickness in fishes

Many astronauts become motion sick during the first 2-3 days of a space mission. On earth, motion sickness consists of a malaise (often leading to vomiting) felt when the body is suddenly accelerated or decelerated or when it changes its direction of movement, especially when information coming from the eyes suggests to the brain that no such motion should take place. Sea sickness is a typical example. In the case of astronauts, the symptoms are the same, but the cause is different: the problem arise because of movements performed in weightlessness. In this case the illness is called "space motion sickness". Astronauts eventually adjust and get better after a few days. However, after landing on earth they often go through another bout of sensory-motor disorders, again for a few days.

Fish have not been reported to vomit in space or during parabolic flights. However, the occurrence of looping – a quantifiable behaviour easily witnessed – follows a similar timeline to that of space motion sickness. Therefore it is thought that fish could serve as an animal model to study space motion sickness and possibly find ways to alleviate it.[5]

Note in passing that people – back on earth – who regularly move fish in transport tanks do sometimes see their fish vomiting while in transit, especially when the tanks are roughly shaken. This seems to be a case of motion sickness. Fish vomiting in transit form the basis of claims to the effect that even fish can get seasick. A more accurate statement would be that even fish can get motion sick.

The first vertebrate mating in space

In the 1990s, a team of Japanese scientists headed by Kenichi Ijiri explored the possibility of sending more fish in space, this time aboard the space shuttle Columbia.[6] The idea was to see if fish could be induced to mate successfully in the absence of gravity (and, by the same token, to provide the first example of a successful vertebrate mating in space). The fish species they chose was the medaka (*Oryzias latipes*), a tough, prolific breeder and a very popular pet fish in Japan. As a preliminary step, the scientists observed the behaviour of medaka during parabolic flights. What they saw was some good old looping. This was not surprising (up to then all fish species had looped in zero or near-zero gravity) but still it was disheartening because it is hard to imagine two fish courting and mating successfully while looping. Even if the medaka were to settle down after a few days, as the mummichogs had done aboard Skylab, they might still not mate because of the general exhaustion and lack of eating resulting from all the looping. But the scientists persevered: they took a great number of medaka on parabolic flights until they found some that did not loop. Then back in the lab they bred those few individuals to create a strain of non-loopers from which they could select the future medaka-astronauts.

Interestingly, these fish refrained from looping only when there was light. If kept in the dark during parabolic flights, all medaka looped (the scientists observed the fish under infrared light and with infrared goggles). Ijiri and his team posited that non-loopers were particularly predisposed towards using light as a cue for maintaining position. Indeed, when submitted to visual tests, the non-loopers scored particularly well. (One such test consists of placing a fish in a circular tank with rotating walls. The walls are painted with vertical stripes. When the walls rotate, the fish have a tendency to follow the stripes and thus swim around the tank – this is the so-called "optomotor response", often explained with the argument that trying to stay at a constant distance from a landmark may be a way to maintain position in a current.[7] Fish with good vision keep swimming around the tank even when the walls rotate very quickly, whereas fish with poorer vision soon see the rotating stripes as a blur and stop moving.)

When medaka are in the mood, they can mate and produce eggs every day. The Japanese researchers selected two non-looping males and two non-looping females who were particularly assiduous at breeding. These were placed in a special enclosed aquarium that was loaded on board the space shuttle Columbia some 30 hours before its launch in July 1994. Lift-off took place without a hitch and already 24 h into the mission a few eggs could be seen inside the aquarium (the aquarium had been built so that a current would sweep any free-floating eggs into a small compartment where a mesh protected the eggs against any cannibalistic attack by the adults). On the third day, a male and a female were caught on video in the typical medaka mating posture, the male clasping the female with his fins. The scene was repeated many times during the whole mission, and eggs were steadily produced. On the 12th day of the 15-day mission, the first egg hatched normally. By the time the shuttle landed, the aquarium contained 11 fry and 27 embryonated eggs. All of these eggs hatched successfully within three days of the landing.

Interestingly, for some time after the landing the four adult medaka looked awkward and seemed to have trouble swimming. It took them three days before they returned to normal. All fry, however, swam without any problem.[8] These space-born fry grew up normally and went on mating with one another on earth, and their successive generations have been distributed to elementary schools and school children throughout Japan.

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[1] von Baumgarten, RJ, Simmonds, RC, Boyd, JF, and Garriott, OK, 1975, Effects of prolonged weightlessness on the swimming pattern of fish aboard Skylab 3, Aviation Space and Environmental Medicine 46, 902-906.

[2] Hoffman, R.B., Salinas, G.A., and Baky, A.A., 1977, Behavioral analyses of killifish exposed to weightlessness in the Apollo-Soyuz test project, Aviation Space and Environmental Medicine 48, 712-717.

[3] Mori, S., Mitarai, G., Takabayashi, A., Usui, S., Sakakibara, M., Nagatomo, M., and von Baumgarten, R.J., 1996, Evidence of sensory conflict and recovery in carp exposed to prolonged weightlessness, Aviation Space and Environmental Medicine 67, 256-261.

[4] Anken, R.H., and Rahmann, H., 1999, Effect of altered gravity on the neurobiology of fish, Naturwissenschaften 86, 155-167.

[5] Idem

[6] http://cosmo.ric.u-tokyo.ac.jp/SPACEMEDAKA/E.html

[7] For an entry into the literature on optomotor responses, see: Brain-encysting parasites affect visually-mediated behaviours of fathead minnows, Écoscience 8: 289-293, and references therein.

[8] However, further experiments with medaka on space shuttle flights indicated that fry hatched in space could be less mobile than fry hatched on earth: Niihori, M., Mogami, Y., Naruse, K., and Baba, S.A. 2004, Development and swimming behavior of Medaka fry in a spaceflight aboard the space shuttle Columbia (STS-107), Zoological Science 21: 923-931.