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Swimming behaviour of the upside-down swimming catfish (*Synodontis nigriventris*) at high-quality microgravity – A drop-tower experiment

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Abstract

The catfish *Synodontis nigriventris* often shows a unique swimming behaviour in being oriented upside-down. When swimming near a (e.g., vertical) substrate, however, the animals orient themselves with their ventral side towards this substrate. This tendency is called ventral substrate response (VSR). The VSR does not only override the upside-down swimming behaviour but also the dorsal light response and the ventral light response.

In the course of an earlier drop-tower experiment performed at ZARM (Bremen, Germany) using cichlid fish (*Oreochromis mossambicus*), we had observed that about 90% of the animals revealed sensorimotor disorders (kinetotic swimming) due to the almost complete lack of gravity as a cue for orientation.

In order to further assess the importance of the VSR for postural control in *S. nigriventris* when being located near a substrate, we subjected catfish in relatively small chambers to drop-tower flights. In contrast to our results regarding cichlid fish, *S. nigriventris* showed no kinetotic behaviour. This clearly suggests that the VSR overrides even vestibular input and possibly represents the most important single behavioural response in this species.

Keywords: Utricle; Saccule; Inner ear; Gravity; Postural control; Dorsal light response

1. Introduction

The teleost *Synodontis nigriventris* is an African catfish in a genus with several species that have been noted for their peculiar postural control (Meyer et al., 1976b): When clear above the bottom and not close to underwater objects these animals swim upside-down, likely due to their surface-feeding and facultative air-breathing life-style. It has been suggested that the increased energy cost of surface swimming is offset by exploiting the air–water interface for food and/or air breathing (Blake and Chan, 2007).

Meyer et al. (1976b) have comprehensively analysed the so-called ventral substrate response (VSR) in *S. nigriventris*. The VSR is the tendency shown by some fishes to orient their ventral side towards a substrate and may thus tilt considerably when swimming near vertical walls or even under the ceiling of caves (Meyer et al., 1976a, 1977). It is especially pronounced in *S. nigriventris* and overrides the dorsal light response as well as the ventral light response (DLR/VLR; swimming upside-down, the fish may turn their ventral side towards an illuminated wall; this VLR is rather exhibited than the DLR in this species) (Meyer et al., 1976a,b). Particularly in small aquaria, *S. nigriventris* will rather exhibit a VSR than a DLR/VLR. According to Meyer et al. (1976b), the VSR behaviour of *S. nigriventris* is a more often observed phenomenon than the upside-down swimming because the animals only infrequently swim in mid-water. Ohnishi et al. (1996) have

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reported that most upside-down postures were observed after taking-off from the substrate.

Earlier, we have shown that the residual gravity in the drop-tower (10^{-6} g) at ZARM (Bremen, Germany) is not sufficient for normally swimming cichlid fish *Oreochromis mossambicus* to be used as a cue for orientation (Anken, 2005; Anken et al., 2006); in these fish, a lack of gravitational input leads to severe sensorimotor disorders. They are called kinetoses (kinetotic fish turn around their longitudinal axis – spinning movements – or circle around the ventral or dorsal surface of the body – looping response; see, e.g., Hilbig et al., 2003). In humans, such kinetoses can lead, e.g., to space sickness.

In order to test if the VSR may allow postural control completely devoid of vestibular cues, we decided to subject *S. nigriventris* to a drop-tower experiment and examine, if the animals would show kinetoses.

2. Materials and methods

The drop-tower experiment was performed at ZARM (Zentrum für angewandte Raumfahrttechnologie und Mikrogravitation/Center of Applied Space Technology and Microgravity, Bremen, Germany). In our experiment, 12 juvenile upside-down swimming catfish *S. nigriventris* (overall length ca. 4 cm), which had been purchased at a local dealer, were individually housed within chambers, milled from a block of polycarbonate (dimensions: $L \times W \times D = 80 \times 50 \times 70\ mm^3$, corners rounded, walls flat, content 270 ml, Fig. 1). The relatively small size of the chambers was chosen to induce a VSR and to exclude upside-down swimming. According to Meyer et al. (1976b), a VSR can sometimes be induced up to 4 cm before the animal reaches a wall. Ohnishi et al. (1996) have reported that the catfish showed upside-down swimming when it was apart from the vertical plane over about 3 cm. The small chambers thus did not allow the animals to swim more than 3–4 cm away from a wall, which would have been a prerequisite for upside-down swimming at take-off from the substrate (Ohnishi et al., 1996). The size of the chambers, however, was estimated to be sufficient to possibly induce kinetotic behaviour (in a preliminary study, we examined the behaviour of 4 cm long juvenile cichlid fish and found out that the chambers were appropriately sized to allow kinetotic swimming movements). The chambers were completely filled with water (care was taken to remove even minute air bubbles) in order to avoid an air–water interface, which might have induced the animals to swim with their ventral side close to this interface.

The entire block was illuminated by three 12 W halogen lamps placed atop the chambers to provide a homogeneous illumination directly from above and equipped with a camcorder (SONY CCD-Iris colour camera, provided by ZARM) for video-recording. The device was implemented in the pressurized (atmospheric pressure, ambient temperature 26 °C) drop-capsule. After some 2 h (this time was needed to evacuate the drop-tube and allowed the animals

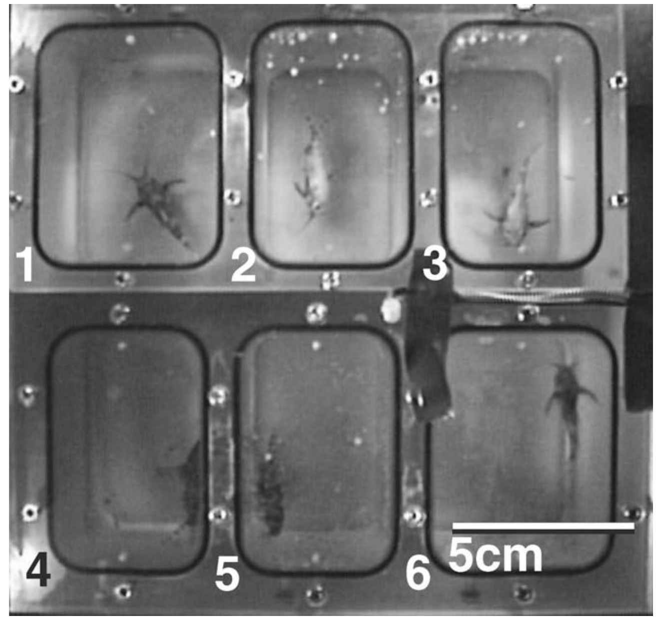

Fig. 1. The hardware used seen from above. This video frame belongs to video footage taken during the microgravity phase of a drop-tower flight, i.e., after release of the drop-capsule and after the animals had performed an escape response. The individual in chamber 1 is slowly moving upside-up close to the bottom of the chamber, whereas the moving animal in chamber 2 just is turning its belly towards the top of the chamber. The other fish are resting close to the walls (chambers 4 and 5), or swimming at the top – upside-down (chamber 3) – or upside-up near the bottom of their chamber (6).

to accommodate to their habitat), the setup was subjected to weightlessness (10^{-6} g, duration some 4.7 s). Subsequently, the behaviour of the specimens was analysed qualitatively using the videorecordings. In detail, animals were observed for 10 s prior to the release of the drop-capsule, during the flight, and for another 10 s after deacceleration of the capsule.

3. Results

Prior to flight, most animals (8) were slowly moving along the boundaries of their chambers, whereas the remaining specimens rested on the substrate. These resting animals kept themselves close to a tank wall (sides, 2 animals) or (1 fish) rested upside-down on the top/ceiling of the chamber or upside-up (1 specimen) on the bottom. The moving catfish swam upright when close to the bottom of their aquarium, tilted to 90° about the longitudinal body axis when swimming horizontally along a tank wall (sides, front and back; at times they also moved vertically head down or head up) or even swam upside-down when being close to the top of their chamber. These fish moved from the bottom to the sides (as well as to the front and to the back) and/or to the top of the aquarium.

The release of the drop-capsule inevitably leads to a mechanical compressive impulse of the capsule. Consequently, all animals showed an escape response. Resting